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Implementation and analysis of a smart submarine in the Active Sonobuoy Model

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IMPLEMENTATION AND ANALYSIS OF
A SMART SUBMARINE IN THE
ACTIVE SONOBUOY MODEL

by
Michael Shawn Wells

September 1991

Thesis Advisor: William J. Walsh

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Implementation and Analysis
of a Smart Submarine in
the Active Sonobuoy Model

by

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Submitted in partial fulfillment
of the requirements for the degree of

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ABSTRACT

The Active Sonobuoy Model simulates a single aircraft attempting to detect and maintain contact on a single submarine. The submarine executes a pre-determined sequence of maneuvers upon counter-detection of the active sonobuoys. Under present methodology these maneuvers are not situation dependent, and do not provide an accurate depiction of reality. The purpose of this thesis is to improve the level of reality of the Active Sonobuoy Model through the implementation of a set of situation dependent maneuver rules for the submarine. This "smart" submarine is then compared to the previously existing "dumb" submarine through the use of hypothesis testing under two measures of effectiveness. The results show that the "smart" submarine provides a more difficult target for the aircraft to detect and sustain contact with than the "dumb" submarine.

THESIS DISCLAIMER

The reader is cautioned that computer programs developed in this research may not have been exercised for all cases of interest. While every effort has been made, within the time available, to ensure that the programs are free of computational and logic errors, they cannot be considered validated. Any application of these programs without additional verification is at the risk of the user.

TABLE OF CONTENTS

I. INTRODUCTION

A. THE MODEL

The Active Sonobuoy Model (ASM) was developed by VITRO CORPORATION in 1988 as an active sonobuoy version of the Rapid Acoustic Detection Simulation (RADS) model. ASM is an active search model which uses sonobuoys as the active sensors. The model simulates one search platform conducting an active sonobuoy search for a single target submarine. The search is conducted on a user input specified area of uncertainty (AOU), based on a time late to datum.

The submarine in the model is completely described by input parameters. The minimum and maximum speeds and depths, as well as target acoustic strength, are specified in the data file by the user. Additionally, the input provides for submarine heading and depth limitations, if desired.

The search platform utilized in the model is an anti-submarine warfare (ASW) aircraft. The specific type of aircraft simulated is dependent upon user input. Platform speed, sensor deployment speed, and sonobuoy monitoring parameters are the primary input data for the search platform.

B. THE PROBLEM

The submarine in the Active Sonobuoy Model executes a preset sequence of evasive maneuvers upon counter-detection of one or more sonobuoy(s). This sequence of maneuvers is specified in the input data and could cause the submarine to travel on a course that takes it toward the active sonobuoy. This type of reaction by the submarine improves the probability of detection of the submarine by the sonobuoy(s) and is not indicative of a real world submarine response. The intent of this thesis is to enhance the Active Sonobuoy Model by developing situation dependent evasive maneuvers for the submarine, and then demonstrate that these maneuvers provide an improved submarine capability to break and avoid sonobuoy contact.

There exists two distinct possibilities for modifying the submarine reaction to sonobuoy counter-detection. The simplest method would be to cause the submarine to execute a random sequence of course, speed, and depth maneuvers of random time duration. The drawback of this approach is that the submarine could still choose a course that takes it toward one or more of the sonobuoys. The more dynamic, and realistic, approach is to provide the submarine with a maneuver response appropriate to the situation. In the simplest case of a single active sonobuoy, the appropriate response would be to choose a course directly away from the

buoy. This approach makes the 'dumb' submarine into a 'smart' submarine by providing a set of rules to conduct sonobuoy evasion.

C. GENERAL DEVELOPMENT OF SOLUTION

A goal of this thesis is to provide the model's submarine with situation dependent maneuver responses that improve the capability to break and avoid detection. The submarine course and depth will be chosen based upon the number and bearing of detected sonobuoys. This solution implies that the submarine has some, as yet unspecified, level of intelligence. The issue of precisely how much intelligence will be further discussed in Chapter III.

The model data for the submarine requires the input of minimum and maximum speeds. Since the model examines only active search, the obvious choice of speeds is the maximum speed which increases the range from detected sonobuoys as rapidly as possible. This may not be consistent with reality since the presence of passive sensors is likely. Also, the submarine's ability to detect sonobuoys is greatly reduced at high speeds. In order to facilitate the possible presence of passive sensors without actually implementing them in the model, the submarine speed is chosen based on depth and the submarine's relationship to the layer (above or below).

D. MEASURES OF EFFECTIVENESS

The Active Sonobuoy Model currently contains two measures of effectiveness for the sonobuoys. The probability of detection (Pd) is computed for each individual sonobuoy, as well as the overall Pd for all sonobuoys deployed. The hold contact time for each individual sonobuoy is also collected. The hold contact time for a sonobuoy is the total amount of time that the sonobuoy detects the submarine.

In order to provide a simple comparative measure, a third MOE, detection count proportion, was implemented in the model. This MOE consists of a count of the total number of submarine detections by the active sonobuoys divided by the total number of sonobuoy pings.

The hold contact time and the detection count will be utilized to conduct a statistical comparison of the results from the "dumb" and "smart" submarines. In the case of the hold contact time MOE, the hold contact time counter is incremented by the amount of the time step for each time step during which one or more of the sonobuoys holds contact on the submarine. For example, if one sonobuoy is able to hold contact on the submarine for the entire duration of a replication, the hold contact time would be equal to the total time of the replication.

The results from the model will be analyzed using hypothesis testing. The hypotheses will be formed using the data from the "dumb" submarine. The data from the "smart"

submarine will then be tested under the null hypothesis that the number of detections, for example, is greater than or equal to the number of detections for the "dumb" submarine. The alternate hypothesis will be that the MOE of interest is less than the corresponding MOE for the "dumb" submarine. The goal for each test is to reject the null hypothesis.

II. DESCRIPTION OF THE MODEL

A. GENERAL DESCRIPTION

The Active Sonobuoy Model is an active search model in which a search platform attempts to detect and track a single target submarine. The search is conducted in a user specified area of uncertainty (AOU). The acoustic conditions in the AOU are specified in a set of input tables which contain the reverberation, ambient noise, and propagation losses versus depth. Thus, the user may manipulate the acoustic inputs to provide a very accurate representation of the particular area of interest.

The general flow of the model consists of a loop containing four basic steps. In the first step, the submarine actions are conducted. Any necessary changes in heading, depth, or speed are implemented, and sonobuoy counter-detection conditions are checked. The second step consists of actions involving the search platform and the sonobuoy patterns. The sonobuoy detection parameters are checked and expired sonobuoys are replaced. Data collection is the third step. The probability of detection, hold contact time, and detection count is updated for each sonobuoy. The final step is a check of the stopping conditions. The stopping conditions are specified by user input. The user indicates

which one of two available stopping conditions will be utilized. The two conditions are: stop upon reaching maximum time, and stop upon initial submarine detection. All data collection runs for this thesis were conducted utilizing the maximum time stopping condition.

B. INPUT DATA

1. Environment

The acoustic environment in the model is described by user input propagation loss, reverberation, and ambient noise tables. Bottom and thermal layer depths are included also. There is a propagation and reverberation table for each of three possible conditions of the sensor and target, in terms of depth relative to the thermal layer. The three conditions represented are sensor and target above layer, sensor and target below layer, and sensor and target on opposite sides of the layer. This last condition is often referred to as across layer. The tables contain values, in decibels, for the appropriate condition based on the range between the sensor and the target.

The ambient noise table is used to represent the acoustic disturbances which are generally present in the ocean environment. The source of this noise could range from merchant shipping traffic to snapping shrimp. The values are entered in the table based on depth.

2. Sonobuoys

The model uses active sonobuoys as the acoustic sensors. Through manipulation of the input data, the user can make the model accurately depict any one, or group, of active sonobuoys. The segment of input which describes the sonobuoys consists of primarily two sections.

The first of these two sections contains the parameters for the patterns in which the sonobuoys will be deployed. The user must input the number of patterns, the number of sonobuoys in each pattern, and the depth of each sonobuoy. Additionally, the replacement criteria for expired sonobuoys must be specified.

The second section describes the performance of the sonobuoys. Inputs in this section include buoy lifetime, duty cycle, pulse length, and reliability. The sonobuoy detection criteria must be specified also. The user must determine the percentage of pings which must be returned in order for a detection to occur.

3. Platforms

The model simulates two classes of platforms, aircraft and submarines. The submarine is the target of the search and the aircraft conducts the search. The model makes no assumptions about platform performance; each platform is completely described by user input.

The input parameters for the submarine specify its maneuverability and acoustic characteristics. Maneuverability is described by rates of change for heading, speed, and depth, as well as, the minimum and maximum speeds and depths. The acoustic performance and signature of the submarine are described by target strength (in db) and a table of self noise versus submarine speed.

The aircraft platform is described by speed and sonobuoy processing capability. The user inputs a single speed for the aircraft, and the model assumes that the aircraft will maintain that speed throughout the search. Inputs for recognition differentials (noise and reverberation) and estimate accuracy describe the processing capability. The estimate accuracy inputs are used as plus or minus bounds on the aircraft's ability to determine submarine depth, speed, and heading.

C. PROCESSING

The most important part of the model, in relation to this thesis, is the method used to determine when and if detections occur. The model uses the active (equations 1 and 2) and passive (equation 3) sonar equations solved for signal excess to accomplish this determination.

$$SIGNAL\ EXCESS = SL - PL - AN + DI + TS - RD \tag{1}$$

$$SIGNAL\ EXCESS = SL - PL - RL + TS - RD \tag{2}$$

$$SIGNAL\ EXCESS = SL - (AN + SN) - PL - RD \tag{3}$$

The terms used in the sonar equations are as follows:

- SL : signal source level
- PL : propagation loss
- AN : ambient noise
- DI : directivity index
- TS : target strength
- RD : recognition differential
- RL : reverberation level
- SN : self noise

The term, (AN + SN), in equation three is enclosed in parentheses to indicate that the two terms are power summed to determine the dominating condition. The active sonar equation is solved for the noise limited and reverberation limited conditions, and detection occurs when the signal excess term in both equations is positive. The passive equation is used to determine when the submarine has detected a sonobuoy, and detection occurs when the signal excess term is positive. In order to avoid ambiguity, when the signal excess term(s) is positive, the ping will be referred to as a successful ping.

The model provides for the dynamics of operator and machine interaction when determining detections. This is accomplished through the use of a detection count criteria. The user specifies the number of successful pings required for

the sonobuoys, or the submarine, to achieve detection. For example, the submarine may have to detect three out of four pings from a sonobuoy in order to determine that the sonobuoy is present. In the case of the aircraft, the user specifies the number of successful pings required to achieve detection of the submarine, as well as the number of successful pings required to maintain detection, or hold contact.

D. FURTHER INFORMATION

The information presented in this chapter is not intended as a stand-alone instruction manual on the ASM. For this reason, descriptions of some of the input parameters have not been presented. The reader is directed to reference 1, The Active Sonobuoy Model User's Guide, for a more indepth description of the model's input requirements and processing algorithms.

III. DEVELOPMENT OF SOLUTION

In order to develop an appropriate solution for a problem, one must fully understand the framework of the problem, and the requirements and limitations of the solution. Accordingly, the first order of business in this chapter will be to examine the problem. The general characteristics of the solution will then be discussed. Finally, the solution will be presented in full detail.

A. BACKGROUND

1. Problem Definition

The basic statement of the problem is that the submarine in the Active Sonobuoy Model does not react to counter-detected active sonobuoys in a realistic manner. The submarine executes a predetermined sequence of course, speed and depth changes. Most importantly, this sequence of maneuvers is not dependent on the tactical situation.

2. Solution Requirements

In general terms, the solution to the problem described above is to develop an algorithm which will provide the submarine with a set of realistic responses to active sonobuoys. Additionally, the solution must be dynamic in regard to the tactical situation, allowing for continual updating of the maneuver response. On the macro level, the

solution is constrained by the operating environment. The Active Sonobuoy Model was designed to be run on a PC. Therefore, the solution must be compact and efficient in order to avoid difficulties with memory limits and processor speed.

The aim of the solution is to provide the submarine with a more realistic maneuver response. This will hopefully enhance the usefulness of the model for both surface and subsurface considerations. However, it is important to note that the development of an optimal maneuver response is not the goal.

3. Factors for Consideration

There are several factors which must be considered when developing a solution. The most important of these factors is the amount of information to be made available to the submarine, or the submarine's "level of intelligence". The other factors involve the choice of course, speed and depth for the submarine.

a. Level of Intelligence

Under actual conditions, the amount of information available to the submarine is dependent upon the specific class of submarine, and the operating area acoustic conditions. Given that the purpose of the thesis was to make the submarine respond in a more realistic manner, thereby making it more difficult to detect and track, the submarine in the model is provided with almost perfect information. This

information includes the bearing, depth, and range of all sonobuoys counter-detected by the submarine. Additionally, the submarine is provided with environmental data concerning the layer depth. An important piece of information not provided to the submarine is the location of buoys which have not been counter-detected by the submarine.

b. Submarine Course

In order to evade the sonobuoys, the submarine must choose a course which will place it on a heading away from the greatest number of sonobuoys. Ideally, the chosen course will be away from all of the sonobuoys. However, this becomes difficult, if not impossible, when the submarine is encircled by the counter-detected sonobuoys.

c. Submarine Depth

The issue of an appropriate evasion depth can become quite complicated when all of the environmental factors and sonar transmission paths are considered. The issue becomes much clearer, and more tractable, when only the basic components of source, target, and layer depths are considered. The source depth is the depth of the acoustic transmitter. In this case, the source depth is the depth of the sonobuoy transducer. The submarine is the target, and it's depth is the target depth.

Utilizing basic underwater sound principles, sound waves (pings) tend to not penetrate the thermal layer due to

the effects of temperature and pressure. If the source is above the layer, a target which is below the layer is much more difficult to detect. The reason behind this phenomena is the requirement for two-way propagation for the active sonobuoy. The sound wave reflected from the target is not strong enough to penetrate the layer on the return trip to the source. The submarine, utilizing passive sensors, is able to detect the portion of the ping that penetrates the layer, and detect the sonobuoy without being detected by the sonobuoy. The opposite case is also true. Therefore, the submarine should attempt to remain on the opposite side of the layer from the sonobuoy.

d. Submarine Speed

In classic ASW, the submarine's speed is limited due to the presence of passive, as well as, active sensors. In this case, there are no passive sensors; however, the submarine's speed is still limited. This limitation is due to the effect of cavitation and self-noise caused by the submarine inhibiting the ability to counter-detect the sonobuoys. The submarine needs to choose the largest possible speed that does not limit counter-detection capability too greatly. Again, utilizing underwater sound principles, the speed must be determined based on submarine depth. In general, the submarine is able to go faster at greater depths while still maintaining adequate counter-detection range.

B. DESCRIPTION OF ALGORITHM

This section details the algorithm developed to determine the submarine evasive maneuver response. The information presented in the first part of this chapter provides the basis for course, speed and depth decisions made in the algorithm described below.

1. Introduction

The algorithm consists of four parts corresponding to the cases of one, two, three, and, four or more counter-detected sonobuoys. After counting the number of sonobuoys to determine the case, the appropriate portion of the algorithm is accessed to determine the evasive maneuver. To accomplish this determination, each of the four cases contains a set of rules for determining course, speed, and depth.

2. The Cases

a. One Sonobuoy

The case of one counter-detected sonobuoy is quite trivial. The appropriate evasion course is that course directly away from the sonobuoy, as illustrated in Figure 1.

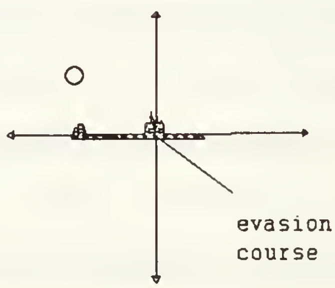

Figure 1. One Sonobuoy Evasion.

The proper depth is on the opposite side of the layer from the sonobuoy. The choice of speed for the one sonobuoy case, and the other cases, is based on the relation of the chosen depth to the layer depth. The submarine has two speeds; one for above the layer and one for below the layer. When operating above the layer, the submarine will go either 15 knots or minimum speed, whichever is greater. Conversely, the submarine will go the lesser of 25 knots and maximum speed when below the layer. These two speeds were chosen based upon the input values for submarine self-noise.

b. Two Sonobuoys

The two sonobuoy case is more involved than the single buoy case. This case also serves as the base case for the more complex problems of three and four or more sonobuoys.

The process of determining the course involves the geometric relationship of the buoys and the submarine. The appropriate course must lie in the region contained by the bearings from the sonobuoys to the submarine as shown in the hatched zone of Figure 2.

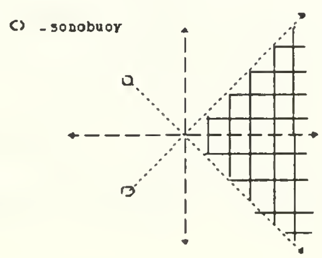

Figure 2. Region of Evasion Courses

The course is chosen by determining the appropriate point in the region to steer towards and then solving for the course to that point. The procedure for determining the point is illustrated in Figure 3. For ease of reference, the submarine has been placed at the origin. First, one of the sonobuoys is reflected (starting with either sonobuoy results in the same solution) through the submarine, but only to the distance equivalent to the range from the submarine to the other sonobuoy (point A). Then, the other sonobuoy is reflected in the same manner (point B). Finally, the vector determined by point A and the submarine is translated to point B, producing point C. Point C, the way-point, is the point toward which the submarine must steer. The circles in Figure 3 represent the sonobuoys.

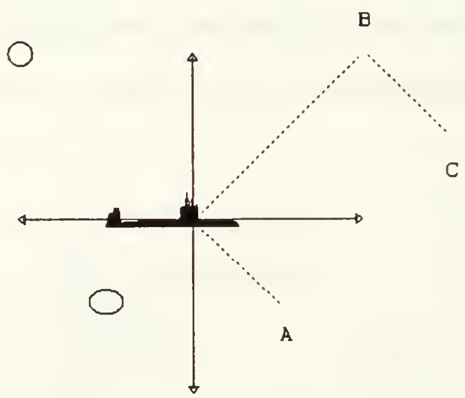

Figure 3. Determining Way-point

Knowing the coordinates of point C and the submarine, determining the course to the way-point becomes a simple trigonometry problem in which the solution is dependent upon the quadrant. Figure 4 illustrates the method used to determine the course. In this figure, SBX and SBY represent the coordinates of the submarine, and TEMPX and TEMPY represent the coordinates of the way-point. The solution is determined based on the relationship between the current x-y coordinates and the way-point x-y coordinates. This relationship determines the quadrant of the way-point, relative to the submarine.

Having determined the appropriate course, the depth must then be determined. The evasion depth is conditioned on the depths of the sonobuoys. If both sonobuoys are above the layer, then the submarine depth will be below the layer, and vice versa. As implemented, the submarine will go to either 200 feet below the layer or 100 feet above the layer, whichever is appropriate. For the case where both sonobuoys are not on the same side of the layer, the submarine will go to the opposite side of the layer as the closest sonobuoy.

<u>c. Three Sonobuoys</u>

The three sonobuoy case can be divided into two sub-cases. The submarine is either inside of the triangle described by the three sonobuoys, or the submarine is outside of the triangle.

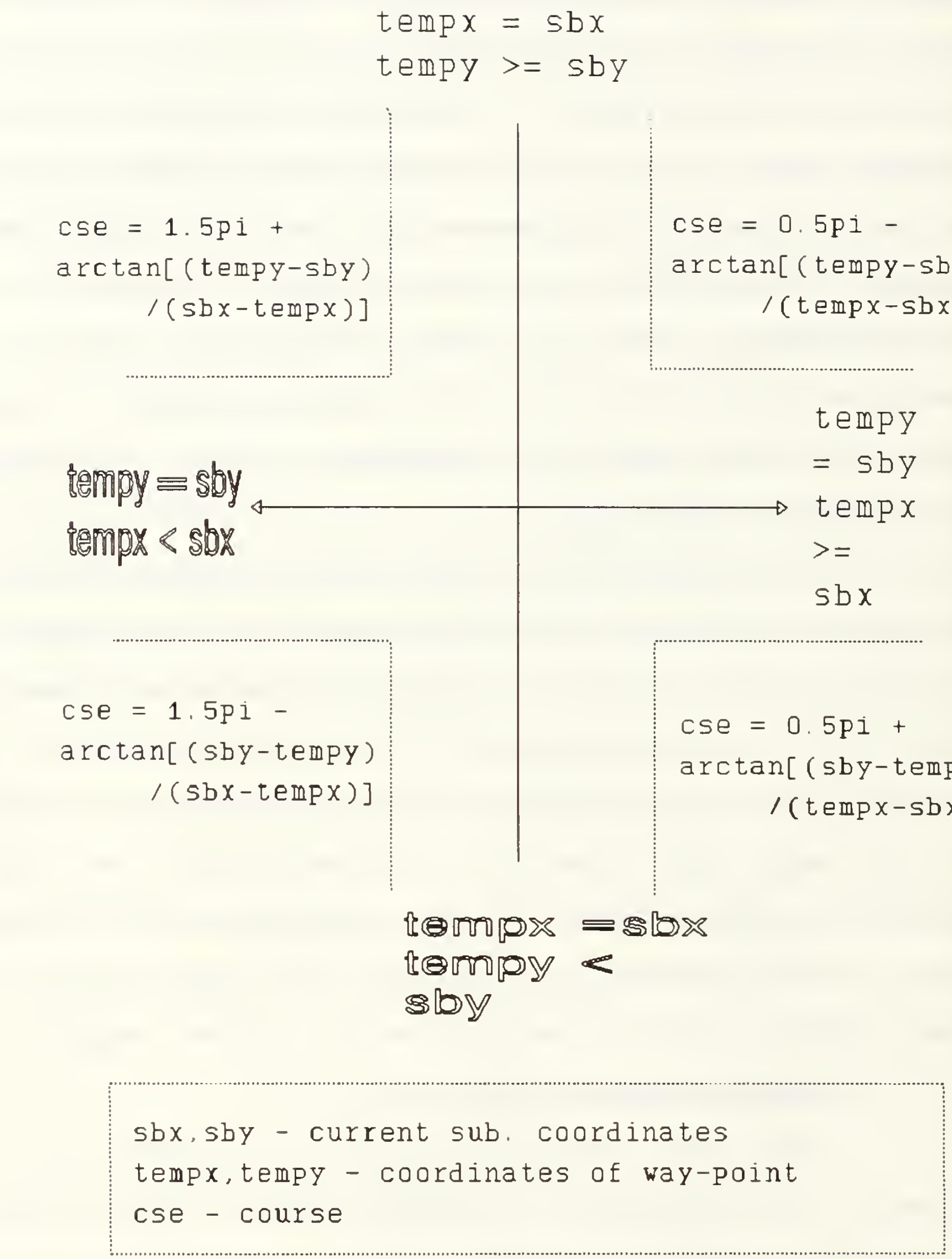

Figure 4. Determining Course to Way-point.

The first step is to determine which sub-case applies. This is done by summing the angles between the buoys. If the sum of the angles is not equal to 2*pi, then the submarine is not in the triangle. When the submarine is not in the triangle, the solution is found by utilizing the two sonobuoy procedure with the two closest sonobuoys.

If the submarine is inside of the triangle, the course is determined by bisecting the largest angle between the sonobuoys. In this way, the submarine attempts to reduce the problem to the two sonobuoy case as quickly as possible while opening the range to the closest sonobuoy.

Depth is determined in the same manner as in the two sonobuoy case. If all of the sonobuoys are above, or below, the layer, the submarine will maneuver to the opposite side of the layer. If all of the buoys are not on the same side of the layer, the submarine will maneuver to the opposite side of the layer from the closest sonobuoy.

d. Four or More Sonobuoys

The case of four or more sonobuoys is similar in nature to the three sonobuoy case. The submarine must either be inside, outside, or on an edge of the figure described by the sonobuoys. However, the determination of inside or outside is slightly different than in the three sonobuoy case.

The sonobuoys are first sorted into increasing bearing order. This step is required to allow the

determination of the angles between adjacent sonobuoys. The term adjacent sonobuoys refers to two sonobuoys between which there are no other sonobuoys. If the angle between any two adjacent sonobuoys is equal to pi, then the submarine is on an edge. In this case, the course is determined by heading 90 degrees away from the edge. If the submarine is not on an edge and the sum of the angles is not equal to 2*pi, then the submarine is not in the figure. This case is reduced to the two sonobuoy case by considering only the two closest sonobuoys and solving appropriately. If the submarine is in the figure (the sum of the angles equals 2*pi), the course is chosen in the same manner as the three sonobuoy case where the submarine was inside of the figure. The bisection of the largest angle between adjacent sonobuoys becomes the new course.

The determination of depth is made as in the previous cases. If all of the sonobuoys are on the same side of the layer, the submarine will go to the side of the layer away from the sonobuoys. Otherwise, the submarine will go to the side of the layer away from the closest sonobuoy.

IV. MEASURES OF EFFECTIVENESS

A. INTRODUCTION

The algorithm that was implemented to improve the level of reality of the submarine's evasive response was presented in Chapter III. In order to determine the effectiveness of the algorithm, a method of comparison between the "dumb" and "smart" submarines must be developed. This chapter presents three measures of effectiveness. Two of these MOE's will be used to compare the two submarines. The three MOE's are probability of detection, detection count, and hold contact time.

B. PROBABILITY OF DETECTION

The probability of detection (Pd) MOE is a measure of the ability of the active sonobuoys to detect the submarine. Since Pd is a probability, it's value must lie in the range from zero to one. The use of Pd as an MOE has some interesting implications. A closer examination of Pd, as implemented in the model, is required before these implications can be discussed.

In the Active Sonobuoy Model, Pd is computed as follows. Each of the sonobuoys is checked each iteration, and, if any sonobuoy was able to detect the submarine, a counter is incremented. After the desired number of iterations, this

counter is divided by the number of iterations yielding an overall Pd for all of the sonobuoys deployed.

Since Pd, in this instance, is a measure of the effectiveness of the sonobuoys, as a whole, it is not sensitive to fluctuations in the performance of individual sonobuoys. As long as any one sonobuoy in the group is able to detect the submarine, at any time during an iteration, the Pd counter will be incremented. However, the counter can be incremented only once each iteration. The ability of a single sonobuoy to detect the submarine repeatedly, or not at all, is not apparent. Thus, Pd is not a good measure. This issue becomes important when one is interested in the submarine's ability to break contact, as well as, avoid detection.

C. DETECTION COUNT

The detection count MOE is similar to Pd. However, detection count attempts to capture information about the submarine's ability to break contact after initial detection and to avoid detection by additional sonobuoys. This is accomplished by updating the detection counter each time a sonobuoy achieves a detection. Additionally, a count is maintained of all opportunities to detect. The detection count MOE is computed by dividing the total number of detections by the number of opportunities to detect.

The detection count MOE, like Pd, is a probability. However, the detection count MOE is more dependent upon the individual sonobuoys than upon the sonobuoy field as a whole. Therefore, the detection count provides more information about the dynamics of the interaction between the sonobuoys and the submarine than Pd was able to provide. Since this interaction is the focus of the algorithm, the detection count MOE would appear to provide a good indication as to the success, or failure, of the evasion algorithm.

D. HOLD CONTACT TIME

Hold contact time is the second MOE under which the "dumb" and "smart" submarines were compared. Hold contact time is a measure of the total amount of time that the sonobuoys were able to maintain contact with the submarine. This MOE provides a means of comparing the two submarines ability to escape after initial detection.

Hold contact time is determined as follows. At each time step, the sonobuoys are checked to determine if any of them hold contact on the submarine. If one or more sonobuoys hold contact on the submarine, the total hold time counter is incremented by the current time step. Thus, as long as any one sonobuoy holds contact on the submarine during a time step, that time step is added to the total hold contact time.

The hold contact time summation is an exclusive sum. In other words, the number of sonobuoys holding contact at the

same time is not important, as long as at least one sonobuoy holds contact. Thus, hold contact time attempts to measure the ability of the submarine to evade the sonobuoy pattern in an expeditious manner.

The measurement of the submarine's ability to evade the sonobuoy pattern as a whole, in as little time as possible is, in theory, quite similar to the Pd measure discussed earlier. The primary difference is that the hold contact time provides a more useful, continuous measure as opposed to Pd. This is due to the fact that Pd, once a detection has been achieved during a replication, discards any further information about detections. Conversely, hold contact time presents a more complete picture about the interaction between the sonobuoys and the submarine since it is updated continuously as more information becomes available. This additional information about the submarine's ability, or, inability to evade the sonobuoys is critical to determining the effectiveness of the evasion algorithm.

V. TESTING, METHODOLOGY AND ANALYSIS

In this chapter the specific scenarios under which the data collection runs will be conducted are described, and the testing methodology is presented. Finally, the analysis of the collected data is conducted.

A. SCENARIO DESCRIPTION

1. Platforms

The platforms represented in the simulation are generic in type. The aircraft operates at a speed of 250 knots, indicative of a fixed wing aircraft. The aircraft has a time late to datum of zero minutes to facilitate rapid detection and trigger the evasive response. The aircraft recognition differentials for both noise and reverberation are set at 15 db. The one sigma values for estimates of speed, heading and depth are set at 5 knots, 20 degrees, and 50 feet, respectively. The submarine has minimum and maximum speeds of 3 and 30 knots, and minimum and maximum depths of 60 and 1300 feet. The submarine starts the simulation at an arbitrarily chosen speed and depth of 8 knots and 400 feet. The submarine's initial course is chosen at random by the model. The submarine recognition differential is -10 db and the directivity index is 10 db.[Ref. 1:p. 15]

2. Environment

The environmental conditions for the simulation were arbitrarily chosen, but are indicative of typical ocean basin conditions. The propagation, reverberation, and ambient noise values are contained in Appendix A. Although the environmental conditions play an important role in detection capability, they are held constant across all iterations. Thus, as long as the sonobuoys, and submarine, are able to detect, the impact of the reality of the conditions is minimal.

3. Sonobuoys

The sonobuoys represented in the simulation are not indicative of any specific real sonobuoy. The parameters for the sonobuoys were chosen to establish an approximate 3 mile MDR. The specific values utilized are contained in Appendix A.[Ref. 1:p. 13]

The deployment patterns for the sonobuoys were held constant for the "smart" and "dumb" submarine to facilitate the analysis. Each submarine was tested against three different sonobuoy patterns. The three patterns are shown in Figures 5-7. The scale marks on the x and y axes of the figures indicate 1.5, 3, and 2.5 nautical mile ranges, respectively.

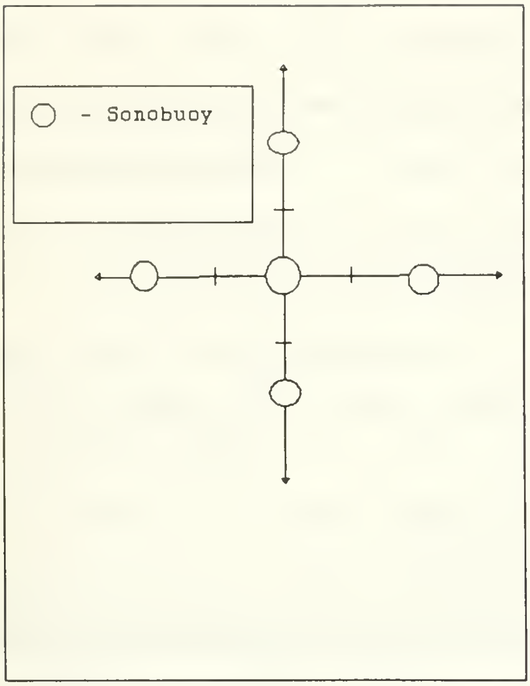

Figure 5. Test Pattern One.

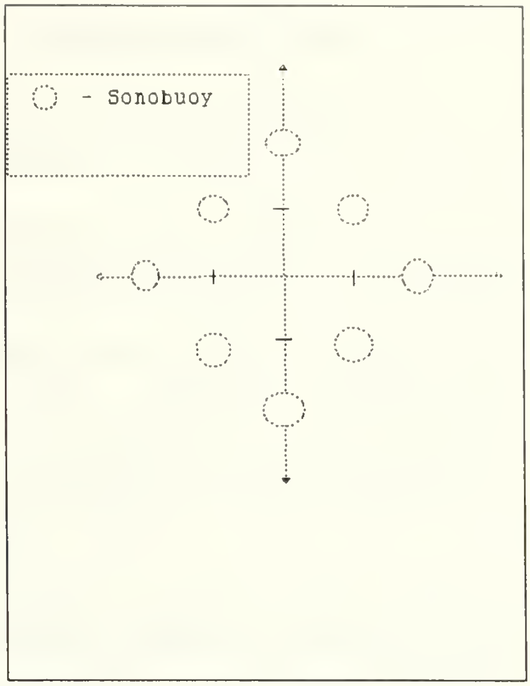

Figure 6. Test Pattern Two.

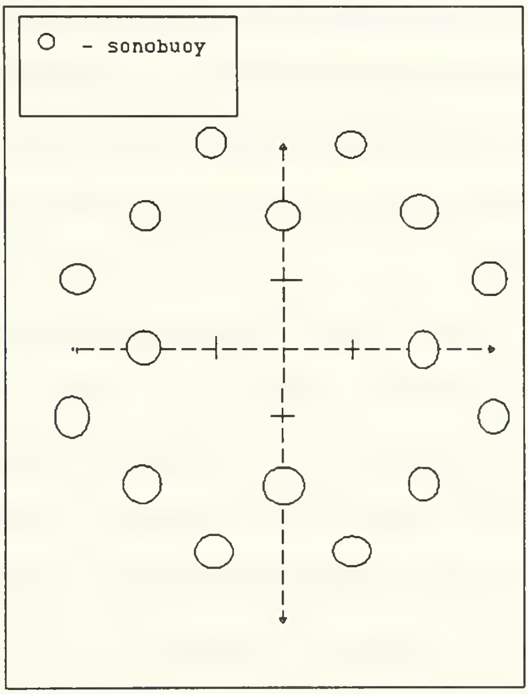

Figure 7. Test Pattern Three.

B. TEST DESIGN

1. Detection Count

The test design for the detection count MOE is structured around a hypothesis test. The basic format for this hypothesis test is based on the null hypothesis that the proportion of detections for the "dumb" submarine is less than or equal to the proportion of detections for the "smart" submarine. Looking at the means of the proportions, this hypothesis can be stated as

$$H_o\colon \overline{p}_d \leq \overline{p}_s. \tag{4}$$

where $\overline{p}_d$ and $\overline{p}_s$ are the mean detection proportions for the "dumb" and "smart" submarines. Since each sample point for the "dumb" submarine is obtained under the same set of conditions as the corresponding sample point for the "smart" submarine (the random seeds and all parameters are the same), a paired sample approach seems prudent. Assuming a paired sample approach, the paired t-test appears to be an appropriate tool.

The paired t-test requires that a set of assumptions be met. These assumptions are: each sample population is normally distributed, and population variances are equal. Before this test can be applied to the data, a close examination of the appropriateness of the assumptions is necessary.

The normality assumption seems quite reasonable given that the value of interest is the mean difference of the paired samples. The mean difference of the paired samples, $\overline{D}$, is defined as

$$\overline{D}=\frac{\sum (p_{di}-p_{si})}{n} \tag{5}$$

where p_{di} and p_{si} are the paired observations [Ref. 2:p. 380]. By the Central Limit Theorem, $\overline{D}$ follows a normal distribution [Ref. 2:p. 380]. The difficulty with this assumption lies at the lower level of measurement involving the detection counts. Each detection opportunity can be viewed as a Bernoulli trial where the value of p_{di}, for instance, is 0 or 1 depending on the value of signal excess (positive signal excess means a detection has occurred, $p_{di}=1$). However, the probability of a positive signal excess varies with the dynamics of the target and sensor relationship (see Chapter 2 for more information on how the model determines detections). In this case, the Bernoulli trials are not identically distributed, and the Central Limit Theorem does not strictly apply. Although the t-test is robust against departures from normality, the possibility of unreliable results is present [Ref. 2:p. 378].

The samples are obtained under the same basic set of conditions with all parameters being held constant. The source of variability in the samples is based on the random

number seed. Therefore, the assumption of equal population variance is reasonable for this test.

Although the normality assumption may be applied for large sample sizes, the paired t-test is deemed inappropriate for this analysis. Information about the underlying sample distributions is not within the scope of study of this analysis. Therefore, in order to provide a means of comparing the results, a non-parametric method which relaxes the normality assumption is desired. The Wilcoxon signed-rank test meets this requirement.

The Wilcoxon signed-rank test for paired samples is constructed as follows:

1. Rank the absolute value of the differences.
2. Assign rank R_i to each of the absolute differences.
3. Restore the signs of the D_i to the ranks.
4. Calculate <u>W+</u>, the sum of the positive ranks.

The assignment of ranks is conducted from smallest to largest with the smallest difference receiving a value of 1.0, and the largest difference receiving a value of n [Ref. 3:p. 374]. The issue of equal difference values is handled by assigning the average of the ranks which would have otherwise been assigned to each of the equal differences [Ref. 2:p. 520]. Difference values of zero are discarded, and the sample size is reduced accordingly.

The Wilcoxon paired-sample signed-rank test, like the paired t-test, requires that a set of assumptions be met. These assumptions are:

1. independence of sample pairs
2. continuity of underlying variable of interest
3. data measured at higher than ordinal scale
4. distribution of difference scores between pairs (approximately) symmetric

[Ref. 2:p. 525]. The independence of sample pairs is accepted as a reasonable assumption given that the data for of each sample pair is produced by the simulation being run under a different random seed. The individual sample points within each pair are related, but that should not affect independence between pairs. The underlying variable of interest is the proportion of detections, which is continuous in the range 0 to 1, so the continuity assumption is fulfilled. The data is measured in the form of a ratio, thereby meeting the measurement scale assumption. The distribution of the difference scores is assumed to be symmetrical.

The test statistic, W+, is approximately normally distributed for large n [Ref. 2:p. 521]. The statistic for testing the null hypothesis may then be stated as

$$Z=\frac{W-\mu_W}{\sigma_W}. \qquad (6)$$

The terms in equation 6 are defined as follows:

$$W=\sum R_i(+), \tag{7}$$

$$\mu_W=\frac{n(n+1)}{4}, \tag{8}$$

$$\sigma_W=\sqrt{\frac{n(n+1)(2n+1)}{24}} \tag{9}$$

[Ref. 2:p. 521].

The null and alternate hypotheses for the Wilcoxon paired-sample signed-ranks test are slightly different from the hypotheses for the paired t-test. Using the Wilcoxon test, the null hypothesis is that the median (as opposed to mean) difference, M_D, between detection proportions for the "dumb" and "smart" submarines is less than or equal to zero

$$H_o: M_D \leq 0, \tag{10}$$

and the alternate hypothesis is that the median difference is greater than zero

$$H_a: M_D > 0 \tag{11}$$

[Ref. 2:p. 525].

2. Hold Contact Time

The test used to evaluate the hold contact time MOE is a Wilcoxon signed-ranks test similar to the detection proportion test. The test examines the medians of the two samples under the null hypothesis that the median hold contact

time for the "dumb" submarine is less than or equal to the median hold contact time for the "smart" submarine. Like the detection proportion, the paired t-test is not appropriate for this set of data. Once again, the difficulty lies in the underlying distribution of the sample points. The underlying distribution of the sample points is unknown. This lack of knowledge makes the calculation of the test statistic

$$t=\frac{\overline{D}-\mu_D}{s_D} \tag{12}$$

quite difficult. This is due to the fact that μ_D is found using

$$\mu_D=\mu_{h_{di}}-\mu_{h_{si}}. \tag{13}$$

Determination of the values of μ_{hsi} and μ_{hdi} cannot be reasonably accomplished without some prior knowledge of the distribution of h_{di} and h_{si}.[Ref. 3:p. 372]

The only area of difference between this test and the test described above for the detection count is terminology. The individual samples under this test are denoted, as indicated in the preceding paragraph, by h_{di} and h_{si} for the "dumb" and "smart" submarines respectively. Applying this terminology to the Wilcoxon test, the differences, D_i, are calculated by

$$D_i=h_{di}-h_{si}. \tag{14}$$

C. ANALYSIS

The results of the hypothesis testing are presented in Table 1. Each of the hypothesis tests were one-tailed and

TABLE 1. RESULTS OF HYPOTHESIS TESTS.

MOE	HYPOTHESIS	TEST STATISTIC	Z(α)	Reject H_o When
Detection Proportion vs Pattern 1	H_o: $Z_D<0$ H_a: $Z_D>0$	Z_D = 8.612	1.645	$Z_D>=Z(\alpha)$
Detection Proportion vs Pattern 2	same	Z_D = 3.897	1.645	same
Detection Proportion vs Pattern 3	same	Z_D = 2.164	1.645	same
Hold Contact Time vs Pattern 1	H_o: $Z_H<0$ H_a: $Z_H>0$	Z_H = 9.739	1.645	$Z_H>=Z(\alpha)$
Hold Contact Time vs Pattern 2	same	Z_H = 4.848	1.645	same
Hold Contact Time vs Pattern 3	same	Z_H = 2.513	1.645	same

were conducted at the 95% level (α = 0.05) with a sample size of 200. (Due to the discarding of zero difference values, the actual test sizes are slightly smaller than 200. Appendix C contains the data for each test.) The Wilcoxon signed-ranks test rejects for large values of the test statistic. As is shown in Table 1, all of the tests rejected the null hypothesis. An item of interest is that the value of the test statistic is smaller for patterns two and three. A possible cause for this phenomena is the construction of the patterns.

Patterns two and three are more distributed than pattern one thereby allowing the submarine greater area in which to maneuver without being detected. Additionally, the greater number of sonobuoys results in a larger number of pings. The reduced number of detections and the larger number of pings causes the detection proportions to be smaller. The reduction in the value of the detection proportions decreases the value of the differences between the proportions for the "dumb" and "smart" submarines. Thus, the test statistic computed using these differences is a smaller value.

Since the hypothesis test rejects the null hypothesis in each of the cases tested, the possibility exists that the results may be dependent upon one or more of the input parameters. The environmental conditions, sonobuoy patterns, and sonobuoy operating characteristics were held constant for all samples within each test. Thus, the data for both of the submarines was collected under the same conditions. Therefore, since the measures used to compare the submarines focus on their evasive abilities, the most likely candidate to cause bias in the results is the pre-determined path of the "dumb" submarine.

In order to determine if the input path of the "dumb" submarine could be causing the results to be falsely high (remembering that the test statistic is based on the differences between samples, where the difference is found using "dumb" minus "smart"), two additional tests were

conducted. Both of the additional tests were conducted using sonobuoy pattern one. Pattern one was chosen due to the excessively long computer run-time required for patterns two and three. These additional tests were identical in structure to the previous tests; however, the "dumb" submarine was given a different pre-determined path for each test. Thus, two additional sets of maneuvers (course, speed, and depth changes, and time durations) were developed for the "dumb" submarine, and each of these maneuver sets, or pre-determined paths, was tested against the "smart" submarine. The results of these tests are shown in Table 2.

TABLE 2. RESULTS OF ADDITIONAL HYPOTHESIS TESTS.

"Dumb" Sub. Path	MOE	Test Statistic	$Z(\alpha)$ $\alpha = 0.05$
1	Detection Proportion	12.015	1.645
1	Hold Contact Time	12.079	1.645
2	Detection Proportion	11.921	1.645
2	Hold Contact Time	12.075	1.645

These tests were conducted under the same null and alternate hypotheses as the previous tests and with the same sample size. Once again, the null hypothesis is rejected in each case. While it is recognized that an infinite number of pre-determined paths exist and that, for a given pattern, a

specific pre-determined path is optimal, the arbitrary selection of a few of these paths for testing against the "smart" submarine is sufficient to provide meaningful results. This is especially true given that the primary area of interest is to provide maneuvers which are applicable in the general case, and not just against a specific sonobuoy pattern.

VI. CONCLUSION

This chapter presents a review of the purpose of the thesis and the conclusions based on the analyses conducted. Also, areas in which further study may be appropriate are discussed.

A. REVIEW AND CONCLUSIONS

The purpose of this thesis is to improve the level of reality represented in the Active Sonobuoy Model, specifically in the area of the submarine's response to counter-detected sonobuoys. The accomplishment of this purpose was attempted through the implementation of a "smart" submarine; a submarine which has a set of situation dependent maneuvers. This "smart" submarine was then tested against the existing "dumb" submarine utilizing various sonobuoy patterns and "dumb" submarine paths. The results of these tests and the accompanying analyses was presented in Chapter V.

Based on the results of the tests, the natural conclusion is that the "smart" submarine can more effectively evade sonobuoys. Therefore, if reality is perceived to be that a submarine should be difficult to detect and track, the "smart" submarine allows the Active Sonobuoy Model to present a more realistic picture.

B. FURTHER STUDY

The testing conducted in this thesis was not exhaustive. The continued testing against a greater variety of sonobuoy patterns is appropriate. Possible areas of interest include the effect of more widely distributed sonobuoy patterns.

The Active Sonobuoy Model simulates active sonobuoys only. The introduction of passive sonobuoys and bi-static detection would enhance the applicability of the model. The presence of passive sonobuoys would allow the examination of the effect of submarine speed on the submarine's ability to evade a combined passive-active sonobuoy pattern. The modular design of the ASM would help facilitate this enhancement. The merger of the ASM with an existing passive sonobuoy model is one method by which this may be accomplished.

APPENDIX A

This appendix contains the actual computer code used to implement the "smart" submarine. The code consists of five subroutines. The subroutine <u>SEVADE</u> is called from the previously existing subroutine <u>EVADE</u> based on user input at the start of the program. The complete ASM program listing may be found in reference 1.

```
PROCEDURE Sevade;
{This procedure determines the number of detected sonobuoys }
{and then calls the appropriate evasion procedure.          }
{This procedure only executes if there has been a newly     }
{detected sonobuoy since determination of the last maneuver.}


 VAR
  n,m,count      : integer;
  oppos,adjac    : real;
 BEGIN
  IF (newdet) THEN
   BEGIN
     count := 0;
{ determine number of buoys counter-detected }
    FOR n := 1 TO nopats DO
     BEGIN
      FOR m := 1 TO nobuoy[n] DO
       BEGIN
        IF isbpng[n,m] = 1 THEN
         BEGIN
          count := count + 1;
  {Determine range to the counter-detected sonobuoy          }
          oppos := sby - buoyy[n,m];
          adjac := sbx - buoyx[n,m];
          rng[count] := SQRT(SQR(oppos) + SQR(adjac));
          depth[count] := budpth[n,m];
  {Determine bearing to the counter-detected sonobuoy
}             IF buoyx[n,m] < sbx THEN
            BEGIN
             IF buoyy[n,m] < sby THEN
                brg[count] := 1.5*pi + ARCTAN(oppos/adjac);
```

```
          IF buoyy[n,m] > sby THEN
             brg[count] := 1.5*pi - ARCTAN(oppos/adjac);
          IF buoyy[n,m] = sby THEN
             brg[count] := 1.5*pi;
         END;
        IF buoyx[n,m] > sbx THEN
         BEGIN
          IF buoyy[n,m] > sby THEN
             brg[count] := pi/2 + ARCTAN(oppos/adjac);
          IF buoyy[n,m] < sby THEN
             brg[count] := pi/2 - ARCTAN(oppos/adjac);
          IF buoyy[n,m] = sby THEN
             brg[count] := pi/2;
         END;
        IF buoyx[n,m] = sbx THEN
         BEGIN
          IF buoyy[n,m] <= sby THEN
             brg[count] := 0
            ELSE
             brg[count] := pi;
         END;
       END; {isbpng = 1 }
     END;
   END;
{Call the appropriate evasion procedure }
   IF count =  1 THEN S1evade;
   IF count =  2 THEN S2evade;
   IF count =  3 THEN S3evade;
   IF count >= 4 THEN S4evade(count);
{Ensure returned values for heading, depth, and speed are}
{ within limits.                                         }
   IF dsbhdg < 0.0 THEN dsbhdg := dsbhdg + twopi;
   IF dsbhdg > twopi THEN dsbhdg := dsbhdg - twopi;
   IF dsbspd < spdmin THEN dsbspd := spdmin;
   IF dsbspd > spdmax THEN dsbspd := spdmax;
   IF dsbdpt < dptmin THEN dsbdpt := dptmin;
   IF dsbdpt > dptmax THEN dsbdpt := dptmax;
{This section of code determines the amount of change that}
{the submarine can accomplish in each time step in terms  }
{of degrees of course change, feet of depth change, and   }
{knots of speed change }
   IF rateno <> 1.0 THEN
    BEGIN
     hdgdif := dsbhdg - sbhdg;
     IF hdgdif >= 0.0 THEN
      BEGIN
       IF hdgdif <= pi THEN
         hdgsyn := 1
        ELSE
         hdgsyn := -1;
      END
```

```
    ELSE
     BEGIN
      IF hdgdif <= pi THEN
        hdgsyn := 1
       ELSE
        hdgsyn := -1;
     END;
    IF ABS(hdgdif) > pi THEN
       hdgdif := twopi - ABS(hdgdif)
     ELSE
       hdgdif := ABS(hdgdif);
    nohdgs := TRUNC(hdgdif/(hdgrte * delta)) + 1;
    IF dsbspd < sbspd THEN
       spdsyn := -1.0
     ELSE
       spdsyn := 1.0;
    IF dsbdpt < sbdpth THEN
       dptsyn := -1.0
     ELSE
       dptsyn := 1.0;
    IF iprint >= 2 THEN
     BEGIN
      WRITELN(out,time:5:2);
      psbhdg := dsbhdg * raddeg;
      WRITELN(out,' Submarine has maneuvered at ',time:5:2);
      WRITELN(out,'    Heading = ',psbhdg:5:0);
      WRITELN(out,'    Speed   = ',dsbspd:5:1);
      WRITELN(out,'    Depth   = ',dsbdpt:5:0);
      WRITELN(out);
     END;
   END;
{Reset new detection flag. This flag is set to true upon }
{detection of a new sonobuoy in the procedure PINGER     }
   newdet := false;
  END;
 END; {Sevade}

PROCEDURE S1evade;
{This procedure determines evasion course, speed, and    }
{depth for the case of one counter-detected sonobuoy.    }
BEGIN
{New course directly away from sonobuoy                  }
 dsbhdg := brg[1] + pi;
{Determine new depth based on sonobuoy relationship to layer}
 IF lyrdpt > 200 THEN
  BEGIN
   IF depth[1] > lyrdpt THEN
      dsbdpt := lyrdpt - 50
    ELSE
      dsbdpt := lyrdpt + 200;
  END
```

```
   ELSE
    BEGIN
     IF depth[1] <= (dptmax/2) THEN
        dsbdpt := 0.75 * dptmax
      ELSE
        dsbdpt := 0.25 * dptmax;
    END;
  {Determine submarine speed based on chosen depth.        }
   IF dsbdpt >= (dptmax/2) THEN
      dsbspd := 25
    ELSE
      dsbspd := 15;
  END; {S1evade}

 PROCEDURE S2evade;
  {This procedure determines the maneuver for the case of two}
  {counter-detected sonobuoys.                                }
 VAR
  psi1,psi2,opp1,opp2,adj1,adj2,a,o :real;
  tempx,tempy                       :real;
  BEGIN
  {Shift the bearings to the two sonobuoys to the first      }
  {(0-90 degrees) quadrant. This is done to avoid             }
  {difficulties with angles crossing the 0 degree bearing.    }
   psi1 := pi + brg[1];
   psi2 := pi + brg[2];
   IF psi1 >= (1.5*pi) THEN psi1 := psi1 - (1.5*pi);
   IF psi2 >= (1.5*pi) THEN psi2 := psi2 - (1.5*pi);
   IF psi1 >= pi THEN psi1 := psi1 - pi;
   IF psi2 >= pi THEN psi2 := psi2 - pi;
   IF psi1 >= (pi/2) THEN psi1 := psi1 - (pi/2);
   IF psi2 >= (pi/2) THEN psi2 := psi2 - (pi/2);
  {Determine the sides of the triangles formed by the        }
  {(bearing,range) vectors which are translated through the   }
  {submarine.                                                 }
   adj1 := rng[2] * COS(psi1);
   adj2 := rng[1] * COS(psi2);
   opp1 := rng[2] * SIN(psi1);
   opp2 := rng[1] * SIN(psi2);
  {Determine the new course based on the original quadrant    }
  {location of the sonobuoy bearings.                         }
   IF brg[1] < (pi/2) THEN
    BEGIN
     tempy := sby - ABS(adj1);
     tempx := sbx - ABS(opp1);
    END
   ELSE
    BEGIN
     IF brg[1] < pi THEN
      BEGIN
       tempx := sbx - ABS(adj1);
```

```
    tempy := sby + ABS(opp1);
   END
  ELSE
   BEGIN
    IF brg[1] < (1.5*pi) THEN
     BEGIN
      tempx := sbx + ABS(opp1);
      tempy := sby + ABS(adj1);
     END
    ELSE
     BEGIN
      tempx := sbx + ABS(adj1);
      tempy := sby - ABS(opp1);
     END;
   END;
 END;
IF brg[2] < (pi/2) THEN
 BEGIN
  tempx := tempx - ABS(opp2);
  tempy := tempy - ABS(adj2);
 END
ELSE
 BEGIN
  IF brg[2] < pi THEN
   BEGIN
    tempx := tempx - ABS(adj2);
    tempy := tempy + ABS(opp2);
   END
  ELSE
   BEGIN
    IF brg[2] < (1.5*pi) THEN
     BEGIN
      tempx := tempx + ABS(opp2);
      tempy := tempy + ABS(adj2);
     END
    ELSE
     BEGIN
      tempx := tempx + ABS(adj2);
      tempy := tempy - ABS(opp2);
     END;
   END;
 END;
IF sbx = tempx THEN
 BEGIN
  IF sby <= tempy THEN
     dsbhdg := 0
    ELSE
     dsbhdg := pi;
 END;
IF sby = tempy THEN
 BEGIN
```

```
   IF sbx <= tempx THEN
      dsbhdg := pitwo
     ELSE
      dsbhdg := 1.5*pi;
  END;
 IF sbx < tempx THEN
  BEGIN
   IF sby < tempy THEN
      dsbhdg := pitwo - ARCTAN((tempy - sby)/(tempx - sbx))
     ELSE
      dsbhdg := pitwo + ARCTAN((sby - tempy)/(tempx - sbx));
  END;
 IF sbx > tempx THEN
  BEGIN
   IF sby < tempy THEN
      dsbhdg := 3*pitwo + ARCTAN((tempy - sby)/(sbx - tempx))
     ELSE
      dsbhdg := 3*pitwo - ARCTAN((sby - tempy)/(sbx -
                   tempx));
  END;
{Determine new depth based on the sonobuoys relationships to}
{the layer depth. All above or below, go to side of layer   }
{away from the sonobuoys, otherwise go to the side of the   }
{layer away from the closest sonobuoy.                      }
 IF lyrdpt > 200 THEN
   BEGIN
    IF depth[1] > lyrdpt THEN
     BEGIN
      IF depth[2] > lyrdpt THEN
       dsbdpt := lyrdpt - 50
      ELSE
       BEGIN
        IF rng[1] < rng[2] THEN
          dsbdpt := lyrdpt - 50
         ELSE
          dsbdpt := lyrdpt + 200;
       END;
     END
    ELSE
     BEGIN
      IF depth[2] <= lyrdpt THEN
       dsbdpt := lyrdpt + 200
      ELSE
       BEGIN
        IF rng[1] <= rng[2] THEN
         dsbdpt := lyrdpt + 200
        ELSE
         dsbdpt := lyrdpt - 50;
       END;
     END;
   END
```

```
   ELSE
    BEGIN
     IF rng[1] <= rng[2] THEN
      IF depth[1] <= (dptmax/2) THEN
       dsbdpt := 0.75 * dptmax
      ELSE
       dsbdpt := 0.25 * dptmax
     ELSE
      IF depth[2] <= (dptmax/2) THEN
       dsbdpt := 0.75 * dptmax
      ELSE
       dsbdpt := 0.25 * dptmax;
    END;
 END; {S2evade}

PROCEDURE S3evade;
 {This procedure determines the maneuver for the three    }
 {sonobuoy case.  The three buoy case has two sub-cases,  }
 {inside of the figure described, or outside of the       }
 {figure. This determination is made by summing the       }
 {angles between the sonobuoy bearings.  If the sum       }
 {equals 360 degrees (two pi), the submarine is inside.   }

VAR
 a1,a2,a3,triang          :real;
 temp                     :integer;
 same                     :boolean;

 BEGIN
 {Determine the angles between the sonobuoys, using the }
 {submarine as the origin for each bearing.             }
  IF brg[1] < brg[2] THEN
     a1 := brg[2] - brg[1]
    ELSE
     a1 := brg[1] - brg[2];
  IF brg[2] < brg[3] THEN
     a2 := brg[3] - brg[2]
    ELSE
     a2 := brg[2] - brg[3];
  IF brg[3] < brg[1] THEN
     a3 := brg[1] - brg[3]
    ELSE
     a3 := brg[3] - brg[1];
  IF a1 > pi THEN a1 := twopi - a1;
  IF a2 > pi THEN a2 := twopi - a2;
  IF a3 > pi THEN a3 := twopi - a3;
 {Sum the angles to determine inside or out.            }
  triang := a1 + a2 + a3;
 {If not equal to two pi, not inside.                   }
  IF triang <> twopi THEN
   BEGIN
```

```
{Not inside, determine closest two buoys and call s2evade.}
   IF rng[1] > rng[2] THEN
    BEGIN
     IF rng[1] > rng[3] THEN
      BEGIN
       rng[1] := rng[2];
       rng[2] := rng[3];
       depth[1] := depth[2];
       depth[2] := depth[3];
       brg[1] := brg[2];
       brg[2] := brg[3];
      END;
    END
   ELSE
    BEGIN
     IF rng[3] < rng[2] THEN
      BEGIN
       rng[2] := rng[3];
       depth[2] := depth[3];
       brg[2] := brg[3];
      END;
    END;
   S2evade;
  END
 ELSE
{Inside of triangle. Determine largest angle. New course is}
{to midpoint of side with largest angle.                    }
  BEGIN
    IF a1 >= a2 THEN
      IF ((a2 >= a3) OR ((a2 < a3) AND (a1 >= a3))) THEN
         dsbhdg := brg[1] + a1/2
        ELSE
         dsbhdg := brg[3] + a3/2
    ELSE
      IF (a2 < a3) THEN
         dsbhdg := brg[3] + a3/2
        ELSE
         dsbhdg := brg[2] + a2/2;
  END;
{Determine closest sonobuoy for depth determination.        }
IF rng[1] <= rng[2] THEN
   IF rng[1] <= rng[3] THEN
      temp := 1
     ELSE
      temp := 3
  ELSE
   IF rng[2] <= rng[3] THEN
      temp := 2
     ELSE
      temp := 3;
 same := false;
```

```
{Determine depth based on sonobuoy relationship to layer}
{depth.    }
 IF lyrdpt > 200 THEN
  BEGIN
   IF
 ((depth[1]>lyrdpt)AND(depth[2]>lyrdpt)AND(depth[3]>lyrdpt))
    THEN
    BEGIN
     dsbdpt := lyrdpt - 50;
     same := true;
    END;
   IF
 ((depth[1]<lyrdpt)AND(depth[2]<lyrdpt)AND(depth[3]<lyrdpt))
    THEN
    BEGIN
     dsbdpt := lyrdpt + 200;
     same := true;
    END;
   IF NOT(same) THEN
    IF depth[temp] > lyrdpt THEN
     dsbdpt := lyrdpt - 50
    ELSE
     dsbdpt := lyrdpt + 200;
  END
  ELSE
  BEGIN
 {If no layer depth is specified, determine depth based on}
 {closest sonobuoy relationship to maximum submarine depth.}
   IF depth[temp] <= (dptmax/2) THEN
    dsbdpt := 0.75 * dptmax
   ELSE
    dsbdpt := 0.25 * dptmax;
  END;
 {Determine speed based on new depth.                    }
  IF dsbdpt >= (dptmax/2) THEN
   dsbspd := 25
  ELSE
   dsbspd := 15;
 END; {S3evade}

PROCEDURE S4evade(count: integer);
{This procedure determines the maneuver for four or more}
{counter-detected sonobuoys.  The procedure takes as    }
{input the actual number of counter-detected sonobuoys    }
{(count). The maneuver is determined based on one of    }
{three cases existing.  The submarine is either in the  }
{figure, outside of the figure, or on an edge of the    }
{figure. The determination about in or out is the same  }
{as in the three buoy case except that the buoys are    }
{sorted into increasing bearing order before the angles }
{are determined and summed.  The determination of on an }
```

```
{edge is made by examining each adjacent pair of the    }
{sorted sonobuoys to check if the submarine is between  }
{the buoys.                                             }

VAR
 angle,hiang,loang                      :array[1..10] of real;
 z,y,close,high,low,big                  :integer;
 onedge,good,below,same                  :boolean;
 edgeon                                       :array[1..2] of
integer;
 temp                                    :real;

 BEGIN
    z := 1;
 {sort buoys into increasing bearing order }
    WHILE z < count DO
     BEGIN
      FOR y := (z+1) TO count DO
       BEGIN
        IF brg[y] < brg[z] THEN
         BEGIN
 {The arrays containing depth and range information must be}
 {sorted in the same manner as the bearing array in order  }
 {to not lose or confuse the information.                  }
          temp := brg[z];
          brg[z] := brg[y];
          brg[y] := temp;
          temp := depth[z];
          depth[z] := depth[y];
          depth[y] := temp;
          temp := rng[z];
          rng[z] := rng[y];
          rng[y] := temp;
         END;
       END;
      z := z + 1;
     END;
  onedge := FALSE;
  z := 0;
{determine if submarine is on an edge of the figure, i.e.}
{between 2 buoys.}
  WHILE ((NOT(onedge)) AND (z < count)) DO
   BEGIN
      z := z + 1;
      temp := brg[z] + pi;
      IF temp > twopi THEN temp := temp - twopi;
      IF brg[(z+1)] = temp THEN
       BEGIN
        onedge := TRUE;
        edgeon[1] := z;
        edgeon[2] := z+1;
```

```
        END;
    END;
{ check if on the edge between the last and first; not  }
{checked above only check if not already found to be on }
{an edge }
  IF NOT(onedge) THEN
   BEGIN
    temp := brg[count] + pi;
    IF temp > twopi THEN temp := temp - twopi;
    IF brg[(count-1)] = temp THEN
     BEGIN
      onedge := TRUE;
      edgeon[1] := count;
      edgeon[2] := count - 1;
     END;
   END;
{ if not on an edge, check if in the figure or outside of }
{the figure }
  IF NOT(onedge) THEN
   BEGIN
    z := 1;
{ sum up angles of adjacent buoys }
    WHILE z < count DO
     BEGIN
      angle[z] := brg[(z+1)] - brg[z];
      z := z + 1;
     END;
    angle[count] := twopi - (brg[count] - brg[1]);
    temp := 0;
    FOR y := 1 TO count DO
     BEGIN
      IF angle[y] > pi THEN angle[y] := twopi - angle[y];
      temp := temp + angle[y];
     END;
    IF temp = twopi THEN
 {Inside of figure. Determine largest angle and choose      }
 {course to the midpoint of the side with this angle.       }
     BEGIN
       big := 1;
          FOR y := 2 TO count DO
           BEGIN
            IF angle[y] > angle[big] THEN
               big := y;
           END;
       dsbhdg := brg[big] + (angle[big]/2);
     END
    ELSE   { temp <> twopi: not in figure: choose best      }
           {course away from closest two buoys.             }
     BEGIN
      z := 1;
  { place data for closest two buoys in 1st two positions   }
```

```
{of the arrays containing the information on the buoys.  }
    WHILE z < count DO
     BEGIN
      FOR y := (z+1) TO count DO
       BEGIN
        IF rng[y] < rng[z] THEN
         BEGIN
          temp := rng[z];
          rng[z] := rng[y];
          rng[y] := temp;
          temp := depth[z];
          depth[z] := depth[y];
          depth[y] := temp;
          temp := brg[z];
          brg[z] := brg[y];
          brg[y] := temp;
         END;
       END;
      z := z + 1;
     END;
    S2evade;
   END;
 END
ELSE {sub is on an edge. Determine course away from the}
     {remainder of the buoy pattern.                    }
 BEGIN
  y := 1;
  good := TRUE;
  WHILE ((y < count) AND (good)) DO
   BEGIN
    IF ((brg[y] <> brg[(edgeon[1])]) AND
        (brg[y] <> brg[(edgeon[2])]) AND
        ((brg[y] < brg[(edgeon[1])]) OR (brg[y] >
                   brg[(edgeon[2])]))) THEN
         good := FALSE;
    y := y + 1;
   END;
  IF (good) THEN
     dsbhdg := brg[(edgeon[2])] - pitwo
    ELSE
     dsbhdg := brg[(edgeon[2])] + pitwo;
{ determine depth and speed. Depth is determined based }
{on the depths of the buoys. If all of the buoys are   }
{on one side of the layer, go to the other side of the }
{layer. if the buoys are on both sides of the layer, go}
{to the opposite side of the layer from the closest    }
{buoy.  The above applies when there is a layer. if    }
{there is no layer, go to the opposite side of maximum }
{sub depth as that of the closest buoy                 }
 IF lyrdpt > 200 THEN
   BEGIN
```

```
      IF depth[1] <= lyrdpt THEN
         below := true
        ELSE
         below := false;
      same := true;
      z := 2;
      WHILE (same) AND (z <= count) DO
       BEGIN
        IF depth[z] <= lyrdpt THEN
          BEGIN
           IF NOT(below) THEN
              same := false;
          END
         ELSE
          BEGIN
            IF (below) THEN
              same := false;
          END;
        z := z + 1;
       END;
      IF (same) THEN
       BEGIN
         IF NOT(below) THEN
            dsbdpt := lyrdpt + 200
           ELSE
            dsbdpt := lyrdpt - 50;
       END
      ELSE
       BEGIN
        IF depth[close] > lyrdpt THEN
           dsbdpt := lyrdpt - 50
          ELSE
           dsbdpt := lyrdpt + 200;
       END;
     END
     ELSE
     BEGIN
       IF depth[close] <= (dptmax/2) THEN
          dsbdpt := 0.75 * dptmax
         ELSE
          dsbdpt := 0.25 * dptmax;
     END;
{ determine desired submarine speed based on desired depth }
    IF dsbdpt >= (dptmax/2) THEN
       dsbdpt := 25
      ELSE
       dsbdpt := 15;
  END; { of response to being on an edge of the figure }
 END; {S4evade}
```

APPENDIX B

This appendix contains the input data sets for each of the simulation runs. There is a total of 5 input data sets, one for each of the three sonobuoy patterns and one for each of the two additional "dumb" submarine paths.

A. PATTERN ONE INPUT DATA

```
Data Set NO. 1
100.0 442 0 0 0 0 0
10.0 130.0 1.0 5.0
Notional Environment
7500 12 12 600.0
1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0 10.0 11.0 12.0
66.1 72.1 75.7 78.2 80.1 81.7 83.0 84.2 85.2 86.1 87.0 87.7
50.0 50.0 50.0 50.0 50.0 50.0 50.0 50.0 50.0 50.0 50.0 50.0
63.1 69.1 72.7 75.2 77.1 78.7 80.0 81.2 82.2 83.1 84.0 84.7
65.0 65.0 65.0 65.0 65.0 65.0 65.0 65.0 65.0 65.0 65.0 65.0
69.1 75.1 78.7 81.2 83.1 84.7 86.0 87.2 88.2 89.1 90.0 90.7
70.0 70.0 70.0 70.0 70.0 70.0 70.0 70.0 70.0 70.0 70.0 70.0
100.0 200.0 300.0 400.0 500.0 600.0 700.0 800.0 900.0 1000.0
1100.0 1200.0
55.0 55.0 55.0 55.0 56.0 56.0 54.0 53.0 54.0 55.0 56.0 57.0
200.0 15.0 10.0 3.0 3.0 3.0 13.0
0.0 85.0 3.0 2 3 1 3
0.0 0.0 5.0 20.0 50.0
10.0 -10.0 2 3
50.0 70.0 90.0
250.0 0.0 0.0
300.0 0.0 359.0 8.0 500.0 100.0
0.6 10.8 480 0
30.0 2.0 1300.0 60.0
1
1 1.0 10401.0 1.0
1.0 0.1 5 2 1 10401.0 6
0.0 0.0  700 0.0 1
3.0 90.0 500 0.0 1
3.0 180 700 0.0 1
3.0 270 700 0.0 1
3.0 0.0 500 0.0 1
1
18
```

```
45.0 600 20 3 2
0.1 0.1 0.1 0.1
60 -200 -25 5 2
0.1 0.1 0.1 0.1
-30.0 400 25 5 2
0.1 0.1 0.1 0.1
90 -300 -25 3 2
0.1 0.1 0.1 0.1
-120 800 15 10 2
0.1 0.1 0.1 0.1
-60 -400 -25 3 2
0.1 0.1 0.1 0.1
120 400 15 10 2
0.1 0.1 0.1 0.1
-60 0 -15 3 2
0.1 0.1 0.1 0.1
100 200 10 10 2
0.1 0.1 0.1 0.1
90 300 -10 10.0 2
0.1 0.1 0.1 0.1
-30 -500 15 10 2
0.1 0.1 0.1 0.1
-90 200 0 10.0 2
0.1 0.1 0.1 0.1
30 200 5.0 10.0 2
0.1 0.1 0.1 0.1
45 -200 10.0 10.0 2
0.1 0.1 0.1 0.1
-135 150 0 5.0 2
0.1 0.1 0.1 0.1
45 200 5.0 10.0 2
0.1 0.1 0.1 0.1
45 0 0 10.0 2
0.1 0.1 0.1 0.1
-60 -300 -10.0 10.0 2
0.1 0.1 0.1 0.1
```

B. PATTERN TWO INPUT DATA

```
Data Set NO. 2
100.0 442 0 0 0 0 0
10.0 130.0 1.0 5.0
Notional Environment
7500 12 12 600.0
1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0 10.0 11.0 12.0
66.1 72.1 75.7 78.2 80.1 81.7 83.0 84.2 85.2 86.1 87.0 87.7
50.0 50.0 50.0 50.0 50.0 50.0 50.0 50.0 50.0 50.0 50.0 50.0
63.1 69.1 72.7 75.2 77.1 78.7 80.0 81.2 82.2 83.1 84.0 84.7
65.0 65.0 65.0 65.0 65.0 65.0 65.0 65.0 65.0 65.0 65.0 65.0
69.1 75.1 78.7 81.2 83.1 84.7 86.0 87.2 88.2 89.1 90.0 90.7
```

```
70.0 70.0 70.0 70.0 70.0 70.0 70.0 70.0 70.0 70.0 70.0 70.0
100.0 200.0 300.0 400.0 500.0 600.0 700.0 800.0 900.0 1000.0
1100.0 1200.0
55.0 55.0 55.0 55.0 56.0 56.0 54.0 53.0 54.0 55.0 56.0 57.0
200.0 15.0 10.0 3.0 3.0 3.0 13.0
0.0 85.0 3.0 2 3 1 3
0.0 0.0 5.0 20.0 50.0
10.0 -10.0 2 3
50.0 70.0 90.0
250.0 0.0 0.0
300.0 0.0 359.0 8.0 500.0 100.0
0.6 10.8 480 0
30.0 2.0 1300.0 60.0
1
1 1.0 10401.0 1.0
1.0 0.1 8 2 1 10401.0 9
6.0 0.0  700 0.0 1
4.1 45.0 500 0.0 1
6.0 90.0 700 0.0 1
4.1 135.0 500 0.0 1
6.0 180.0 700 0.0 1
4.1 225.0 500 0.0 1
6.0 270.0 700 0.0 1
4.1 315.0 500 0.0 1
1
18
45.0 600 20 3 2
0.1 0.1 0.1 0.1
60 -200 -25 5 2
0.1 0.1 0.1 0.1
-30.0 400 25 5 2
0.1 0.1 0.1 0.1
90 -300 -25 3 2
0.1 0.1 0.1 0.1
-120 800 15 10 2
0.1 0.1 0.1 0.1
-60 -400 -25 3 2
0.1 0.1 0.1 0.1
120 400 15 10 2
0.1 0.1 0.1 0.1
-60 0 -15 3 2
0.1 0.1 0.1 0.1
100 200 10 10 2
0.1 0.1 0.1 0.1
90 300 -10 10.0 2
0.1 0.1 0.1 0.1
-30 -500 15 10 2
0.1 0.1 0.1 0.1
-90 200 0 10.0 2
0.1 0.1 0.1 0.1
30 200 5.0 10.0 2
```

```
0.1 0.1 0.1 0.1
45 -200 10.0 10.0 2
0.1 0.1 0.1 0.1
-135 150 0 5.0 2
0.1 0.1 0.1 0.1
45 200 5.0 10.0 2
0.1 0.1 0.1 0.1
45 0 0 10.0 2
0.1 0.1 0.1 0.1
-60 -300 -10.0 10.0 2
0.1 0.1 0.1 0.1
```

C. PATTERN THREE INPUT DATA

```
Data Set NO. 3
100.0 200 0 0 0 0 0
10.0 130.0 1.0 5.0
Notional Environment
7500 12 12 600.0
1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0 10.0 11.0 12.0
66.1 72.1 75.7 78.2 80.1 81.7 83.0 84.2 85.2 86.1 87.0 87.7
50.0 50.0 50.0 50.0 50.0 50.0 50.0 50.0 50.0 50.0 50.0 50.0
63.1 69.1 72.7 75.2 77.1 78.7 80.0 81.2 82.2 83.1 84.0 84.7
65.0 65.0 65.0 65.0 65.0 65.0 65.0 65.0 65.0 65.0 65.0 65.0
69.1 75.1 78.7 81.2 83.1 84.7 86.0 87.2 88.2 89.1 90.0 90.7
70.0 70.0 70.0 70.0 70.0 70.0 70.0 70.0 70.0 70.0 70.0 70.0
100.0 200.0 300.0 400.0 500.0 600.0 700.0 800.0 900.0 1000.0
1100.0 1200.0
55.0 55.0 55.0 55.0 56.0 56.0 54.0 53.0 54.0 55.0 56.0 57.0
200.0 15.0 10.0 3.0 3.0 3.0 13.0
0.0 85.0 3.0 2 3 1 3
0.0 0.0 5.0 20.0 50.0
10.0 -10.0 2 3
50.0 70.0 90.0
250.0 0.0 0.0
300.0 0.0 359.0 8.0 500.0 100.0
0.6 10.8 480 0
30.0 2.0 1300.0 60.0
1
1 1.0 10401.0 1.0
1.0 0.1 16 2 1 10401.0 17
5.0 0.0 500 0.0 1
7.0 45.0 700 0.0 1
5.0 90.0 500 0.0 1
7.0 135.0 700 0.0 1
5.0 180.0 500 0.0 1
7.0 225.0 700 0.0 1
5.0 270.0 500 0.0 1
7.0 315.0 700 0.0 1
```

```
7.9 340.0 600 0.0 1
7.9 22.5 600 0.0 1
7.9 67.5 600 0.0 1
7.9 112.5 600 0.0 1
7.9 157.5 600 0.0 1
7.9 202.5 600 0.0 1
7.9 247.5 600 0.0 1
7.9 292.5 600 0.0 1
1
18
45.0 600 20 3 2
0.1 0.1 0.1 0.1
60 -200 -25 5 2
0.1 0.1 0.1 0.1
-30.0 400 25 5 2
0.1 0.1 0.1 0.1
90 -300 -25 3 2
0.1 0.1 0.1 0.1
-120 800 15 10 2
0.1 0.1 0.1 0.1
-60 -400 -25 3 2
0.1 0.1 0.1 0.1
120 400 15 10 2
0.1 0.1 0.1 0.1
-60 0 -15 3 2
0.1 0.1 0.1 0.1
100 200 10 10 2
0.1 0.1 0.1 0.1
90 300 -10 10.0 2
0.1 0.1 0.1 0.1
-30 -500 15 10 2
0.1 0.1 0.1 0.1
-90 200 0 10.0 2
0.1 0.1 0.1 0.1
30 200 5.0 10.0 2
0.1 0.1 0.1 0.1
45 -200 10.0 10.0 2
0.1 0.1 0.1 0.1
-135 150 0 5.0 2
0.1 0.1 0.1 0.1
45 200 5.0 10.0 2
0.1 0.1 0.1 0.1
45 0 0 10.0 2
0.1 0.1 0.1 0.1
-60 -300 -10.0 10.0 2
0.1 0.1 0.1 0.1
```

D. ALTERNATE PATH ONE INPUT DATA

```
Data Set NO. 1 Alternate path 1
100.0 200 0 0 0 0 0
10.0 130.0 1.0 5.0
Notional Environment
7500 12 12 600.0
1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0 10.0 11.0 12.0
66.1 72.1 75.7 78.2 80.1 81.7 83.0 84.2 85.2 86.1 87.0 87.7
50.0 50.0 50.0 50.0 50.0 50.0 50.0 50.0 50.0 50.0 50.0 50.0
63.1 69.1 72.7 75.2 77.1 78.7 80.0 81.2 82.2 83.1 84.0 84.7
65.0 65.0 65.0 65.0 65.0 65.0 65.0 65.0 65.0 65.0 65.0 65.0
69.1 75.1 78.7 81.2 83.1 84.7 86.0 87.2 88.2 89.1 90.0 90.7
70.0 70.0 70.0 70.0 70.0 70.0 70.0 70.0 70.0 70.0 70.0 70.0
100.0 200.0 300.0 400.0 500.0 600.0 700.0 800.0 900.0 1000.0
1100.0 1200.0
55.0 55.0 55.0 55.0 56.0 56.0 54.0 53.0 54.0 55.0 56.0 57.0
200.0 15.0 10.0 3.0 3.0 3.0 13.0
0.0 85.0 3.0 2 3 1 3
0.0 0.0 5.0 20.0 50.0
10.0 -10.0 2 3
50.0 70.0 90.0
250.0 0.0 0.0
300.0 0.0 359.0 8.0 500.0 100.0
0.6 10.8 480 0
30.0 2.0 1300.0 60.0
1
1 1.0 10401.0 1.0
1.0 0.1 5 2 1 10401.0 6
0.0 0.0  700 0.0 1
3.0 90.0 500 0.0 1
3.0 180 700 0.0 1
3.0 270 700 0.0 1
3.0 0.0 500 0.0 1
1
20
95.0 300 20 5 2
0.1 0.1 0.1 0.1
-45 -200 -15 5 2
0.1 0.1 0.1 0.1
110 -100 -5 5 2
0.1 0.1 0.1 0.1
-45 300 15 5 2
0.1 0.1 0.1 0.1
-45 -100 0 5 2
0.1 0.1 0.1 0.1
120 400 5 5 2
0.1 0.1 0.1 0.1
-90 200 20 5 2
0.1 0.1 0.1 0.1
-60 0 -15 3 2
```

```
0.1 0.1 0.1 0.1
100 200 10 5 2
0.1 0.1 0.1 0.1
-90 300 10 5.0 2
0.1 0.1 0.1 0.1
30 200 -5 5 2
0.1 0.1 0.1 0.1
-60 200 0 5 2
0.1 0.1 0.1 0.1
-45 200 15 5 2
0.1 0.1 0.1 0.1
-45 -600 -20 5 2
0.1 0.1 0.1 0.1
0 350 0 5.0 2
0.1 0.1 0.1 0.1
170 300 20.0 5 2
0.1 0.1 0.1 0.1
45 0 10 5.0 2
0.1 0.1 0.1 0.1
-60 -300 -10.0 5 2
0.1 0.1 0.1 0.1
85 275 8 5 2
0.1 0.1 0.1 0.1
-135 -100 15 5 2
0.1 0.1 0.1 0.1
0 0 35 5 2
0.1 0.1 0.1 0.1
```

E. ALTERNATE PATH TWO INPUT DATA

```
Data Set NO. 1 Alternate path 2
100.0 200 0 0 0 0 0
10.0 130.0 1.0 5.0
Notional Environment
7500 12 12 600.0
1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0 10.0 11.0 12.0
66.1 72.1 75.7 78.2 80.1 81.7 83.0 84.2 85.2 86.1 87.0 87.7
50.0 50.0 50.0 50.0 50.0 50.0 50.0 50.0 50.0 50.0 50.0 50.0
63.1 69.1 72.7 75.2 77.1 78.7 80.0 81.2 82.2 83.1 84.0 84.7
65.0 65.0 65.0 65.0 65.0 65.0 65.0 65.0 65.0 65.0 65.0 65.0
69.1 75.1 78.7 81.2 83.1 84.7 86.0 87.2 88.2 89.1 90.0 90.7
70.0 70.0 70.0 70.0 70.0 70.0 70.0 70.0 70.0 70.0 70.0 70.0
100.0 200.0 300.0 400.0 500.0 600.0 700.0 800.0 900.0 1000.0
1100.0 1200.0
55.0 55.0 55.0 55.0 56.0 56.0 54.0 53.0 54.0 55.0 56.0 57.0
200.0 15.0 10.0 3.0 3.0 3.0 13.0
0.0 85.0 3.0 2 3 1 3
0.0 0.0 5.0 20.0 50.0
10.0 -10.0 2 3
```

```
50.0 70.0 90.0
250.0 0.0 0.0
300.0 0.0 359.0 8.0 500.0 100.0
0.6 10.8 480 0
30.0 2.0 1300.0 60.0
1
1 1.0 10401.0 1.0
1.0 0.1 5 2 1 10401.0 6
0.0 0.0  700 0.0 1
3.0 90.0 500 0.0 1
3.0 180 700 0.0 1
3.0 270 700 0.0 1
3.0 0.0 500 0.0 1
1
10
125 300 5 10 2
0.1 0.1 0.1 0.1
-35 200 10 10 2
0.1 0.1 0.1 0.1
75 -400 -5 10 2
0.1 0.1 0.1 0.1
25 300 15 10 2
0.1 0.1 0.1 0.1
-45 -200 20 10 2
0.1 0.1 0.1 0.1
100 400 -10 10 2
0.1 0.1 0.1 0.1
-35 -100 5 10 2
0.1 0.1 0.1 0.1
146 350 15 10 2
0.1 0.1 0.1 0.1
-100 -500 -5 10 2
0.1 0.1 0.1 0.1
35 300 -20 10.0 2
```

APPENDIX C

This appendix contains the output data from the simulation runs. There are five data sets corresponding to the five sets of hypotheses tests. Included after each data set are the calculated values for the Wilcoxon test statistic, Z, for the detection proportion and hold contact time. The Pdi and Hdi columns contain the detection proportion and hold contact time difference values. The rank columns contain the rank for each non-zero difference value, and the Ri(+) columns contain the ranks for the positive difference values. A zero in the Ri(+) column indicates a negative difference value.

A. DATA SET ONE - PATTERN ONE

WILCOXON TEST PATTERN ONE

Pdi	abs(Pdi)	RANK	Ri(+)	Hdi	abs(Hdi)	RANK	Ri(+)
0	0			0	0		
0	0			0	0		
0	0			0	0		
0	0			0	0		
0	0			0	0		
0	0			0	0		
0	0			0	0		
0	0			0	0		
0	0			0.1667	0.1667	1	1
0.001	0.001	1	1	0.5	0.5	2	2
-0.002	0.002	2.5	0	1.1666	1.166	3	3
0.002	0.002	2.5	2.5	1.1667	1.1667	4	4
-0.003	0.003	4	0	1.5	1.5	5	5
0.004	0.004	5.5	5.5	-1.6666	1.6666	6	0
0.004	0.004	5.5	5.5	2.1667	2.1667	7	7
0.005	0.005	7.5	7.5	2.5	2.5	8	8
0.005	0.005	7.5	7.5	2.8333	2.8333	9	9
0.006	0.006	10	10	3.1667	3.1667	10	10
-0.006	0.006	10	0	3.3334	3.333	11	11

-0.006	0.006	10	0	3.5	3.5	12	12
0.007	0.007	12	12	3.6667	3.6667	13.5	13.5
0.008	0.008	13.5	13.5	3.6667	3.6667	13.4	13.4
0.008	0.008	13.5	13.5	-3.8333	3.8333	15	0
0.01	0.01	15	15	4.1666	4.1666	16	16
0.011	0.011	16	16	4.3333	4.3333	17	17
-0.012	0.012	17.5	0	4.5	4.5	18	18
0.012	0.012	17.5	17.5	4.6667	4.6667	19	19
0.014	0.014	19.5	19.5	5	5	20	20
0.014	0.014	19.5	19.5	5.1667	5.1667	21	21
0.015	0.015	21.5	21.5	-6	6	22.5	0
-0.015	0.015	21.5	0	-6	6	22.5	0
-0.016	0.016	23.5	0	6.5	6.5	24	24
0.016	0.016	23.5	23.5	6.8333	6.8333	25.5	25.5
0.017	0.017	25	25	6.8333	6.8333	25.5	25.5
0.018	0.018	26	26	7	7	27.5	27.5
-0.019	0.019	27.5	0	-7	7	27.5	0
-0.019	0.019	27.5	0	7.1667	7.166	29	29
0.02	0.02	29	29	7.3333	7.3333	30	30
0.021	0.021	30	30	7.3334	7.3334	31	31
-0.022	0.022	31	0	7.6666	7.666	32	32
0.023	0.023	32	32	-7.6667	7.6667	33	0
0.024	0.024	33.5	33.5	-8.1667	8.1667	34.5	0
0.024	0.024	33.5	33.5	8.1667	8.1667	34.5	34.5
-0.025	0.025	35	0	8.1667	8.166	36	36
0.026	0.026	36	36	-8.3334	8.3334	37	0
0.027	0.027	37.5	37.5	8.6666	8.6666	38	38
0.027	0.027	37.5	37.5	9.5	9.5	39.5	39.5
0.028	0.028	39	39	9.5	9.5	39.5	39.5
-0.029	0.029	40.5	0	-9.8334	9.833	41	0
0.029	0.029	40.5	40.5	10	10	42.5	42.5
-0.03	0.03	42	0	-10	10	42.5	0
-0.033	0.033	43	0	10.3333	10.333	44	44
-0.036	0.036	44.5	0	10.5	10.5	45	45
0.036	0.036	44.5	44.5	10.6666	10.6666	46	46
0.039	0.039	46	46	11.5	11.5	47	47
0.04	0.04	47	47	11.6666	11.6666	48	48
0.041	0.041	48	48	11.8334	11.8334	49	49
0.042	0.042	49	49	12.6667	12.6667	50	50
0.043	0.043	50.5	50.5	13.1667	13.1667	51	51
-0.043	0.043	50.5	0	14	14	52.5	52.5
-0.045	0.045	52	0	14	14	52.5	52.5
-0.047	0.047	53	0	14.3334	14.333	54	54
0.049	0.049	54	54	-15.6667	15.6667	55	0
0.05	0.05	55.5	55.5	16	16	56	56
-0.05	0.05	55.5	0	16.3333	16.333	57.5	57.5
-0.051	0.051	57	0	16.3333	16.333	57.5	57.5
0.052	0.052	58.5	58.5	16.6666	16.6666	59	59
-0.052	0.052	58.5	0	17	17	60.5	60.5
0.053	0.053	60	60	-17	17	60.5	0
0.054	0.054	61	61	-17.1667	17.1667	62.50	

0.056	0.056	62.5	62.5	17.1667	17.1667	62.5	62.5
0.056	0.056	62.5	62.5	17.5	17.5	64	64
-0.057	0.057	64	0	-18	18	65	0
0.058	0.058	65	65	18.5	18.5	66	66
0.063	0.063	66	66	18.6667	18.6667	67	67
0.065	0.065	67.5	67.5	-18.8333	18.8333	68.50	
0.065	0.065	67.5	67.5	18.8333	18.8333	68.5	68.5
0.069	0.069	69	69	19.3333	19.3333	70	70
0.071	0.071	70	70	19.3334	19.3334	71	71
0.072	0.072	71	71	20	20	72.5	72.5
0.073	0.073	72.5	72.5	20	20	72.5	72.5
0.073	0.073	72.5	72.5	-20.5	20.5	74	0
0.074	0.074	74	74	21	21	75	75
0.075	0.075	75.5	75.5	21.1667	21.1667	76	76
0.075	0.075	75.5	75.5	21.3333	21.3333	77	77
0.076	0.076	77	77	-21.5	21.5	78	0
-0.078	0.078	79.5	0	21.6667	21.666	79.5	79.5
-0.078	0.078	79.5	0	21.6667	21.666	79.5	79.5
0.078	0.078	79.5	79.5	-21.8333	21.8333	81	0
0.078	0.078	79.5	79.5	-22.1667	22.1667	82	0
-0.081	0.081	82	0	23.3333	23.333	83	83
0.082	0.082	83	83	23.5	23.5	84	84
0.083	0.083	84.5	84.5	23.6666	23.6666	85	85
0.083	0.083	84.5	84.5	23.6667	23.6667	86	86
-0.085	0.085	86	0	-24	24	87	0
-0.086	0.086	88	0	24.5	24.5	88	88
0.086	0.086	88	88	24.6667	24.6667	89	89
0.086	0.086	88	88	24.8334	24.8334	90	90
-0.087	0.087	90	0	25	25	91	91
0.088	0.088	91	91	25.5	25.5	92	92
0.089	0.089	92	92	25.6667	25.6667	93	93
0.09	0.09	93	93	26	26	94	94
0.093	0.093	94.5	94.5	26.6667	26.6667	95	95
0.093	0.093	94.5	94.5	-26.8333	26.8333	96	0
-0.094	0.094	96	0	26.8333	26.833	97	97
0.096	0.096	97	97	27	27	98	98
0.097	0.097	98.5	98.5	27.1667	27.1667	99	99
0.097	0.097	98.5	98.5	27.3333	27.3333	100.5100.5	
0.098	0.098	100.5	100.5	27.3333	27.3333	100.5	100.5
0.098	0.098	100.5	100.5	-27.5	27.5	102	0
0.1	0.1	102.5	102.5	-28.5	28.5	103.5	0
0.1	0.1	102.5	102.5	-28.5	28.5	103.5	0
0.101	0.101	104.5	104.5	28.6666	28.6666	105.5	105.5
0.101	0.101	104.5	104.5	28.6667	28.6667	105.5	105.5
0.102	0.102	106.5	106.5	29	29	107.5	107.5
0.102	0.102	106.5	106.5	29	29	107.5	107.5
0.103	0.103	108.5	108.5	29.5	29.5	109	109
0.103	0.103	108.5	108.5	29.6666	29.6666	110.5	110.5
0.106	0.106	110	110	29.6666	29.6666	110.5110.5	
0.108	0.108	111	111	30.1667	30.1667	112	112
-0.11	0.11	112	0	30.333	30.333	113	113

0.111	0.111	113	113	30.6667	30.6667	114	114
0.112	0.112	114.5	114.5	-30.8333	30.8333	115.5	0
0.112	0.112	114.5	114.5	-30.8333	30.8333	115.5	0
0.113	0.113	116.5	116.5	31	31	117	117
-0.113	0.113	116.5	0	31.333	31.333	118	118
0.114	0.114	118	118	31.5	31.5	119.5	119.5
0.115	0.115	119	119	31.5	31.5	119.5	119.5
0.117	0.117	120.5	120.5	31.8333	31.8333	121	121
0.117	0.117	120.5	120.5	32.1666	32.1666	122.5	122.5
0.118	0.118	123	123	32.1667	32.1667	122.5	122.5
0.118	0.118	123	123	-32.5	32.5	124.5	0
0.118	0.118	123	123	32.5	32.5	124.5	124.5
-0.119	0.119	125	0	32.833	32.833	126	126
0.12	0.12	126	126	33	33	127	127
0.121	0.121	127	127	33.1666	33.1666	128	128
0.122	0.122	129	129	33.1667	33.1667	129	129
0.122	0.122	129	129	33.3333	33.3333	130	130
-0.122	0.122	129	0	34	34	132	132
-0.123	0.123	132	0	34	34	132	132
0.123	0.123	132	132	34	34	132	132
0.123	0.123	132	132	34.3333	34.3333	134	134
-0.124	0.124	135	0	34.5	34.5	136	136
0.124	0.124	135	135	34.5	34.5	136	136
0.124	0.124	135	135	34.5	34.5	136	136
0.125	0.125	137.5	137.5	35	35	138	138
0.125	0.125	137.5	137.5	36.1667	36.1667	139	139
0.126	0.126	139	139	36.8334	36.8334	140	140
0.127	0.127	140	140	37.6666	37.6666	141	141
0.128	0.128	141	141	38.1667	38.1667	142	142
-0.129	0.129	142.5	0	38.5	38.5	143	143
0.129	0.129	142.5	142.5	38.6667	38.6667	144	144
0.13	0.13	144	144	39.1667	39.1667	145.5	145.5
0.132	0.132	145	145	39.1667	39.1667	145.5	145.5
0.133	0.133	146	146	39.3333	39.3333	147	147
0.134	0.134	147	147	39.6667	39.6667	148	148
0.136	0.136	148	148	40.1667	40.1667	149	149
0.137	0.137	149	149	40.8333	40.8333	150	150
0.138	0.138	150	150	41	41	151	151
-0.14	0.14	151	0	41.3333	41.333	152	152
0.141	0.141	152	152	41.3333	41.3333	153	153
0.142	0.142	153	153	42.3333	42.3333	154	154
0.143	0.143	154	154	42.8333	42.8333	155	155
0.144	0.144	155.5	155.5	43.3333	43.3333	156	156
0.144	0.144	155.5	155.5	45.5	45.5	157	157
0.149	0.149	157	157	45.8334	45.8334	158	158
0.152	0.152	158.5	158.5	46.3333	46.3333	159	159
0.152	0.152	158.5	158.5	46.6667	46.6667	160	160
0.153	0.153	160.5	160.5	47.3333	47.3333	161	161
0.153	0.153	160.5	160.5	48.1667	48.1667	162.5	162.5
0.154	0.154	162	162	48.1667	48.1667	162.5	162.5
0.155	0.155	163	163	48.3333	48.3333	164.5	164.5

0.157	0.157	164	164	48.8333	48.8333	164.5	164.5
-0.158	0.158	165	0	49.3333	49.333	166	166
0.159	0.159	166	166	50	50	167	167
0.161	0.161	167	167	50.5	50.5	168	168
0.165	0.165	168	168	51	51	169	169
0.166	0.166	169	169	51.1667	51.1667	170	170
0.168	0.168	170.5	170.5	51.3334	51.3334	171	171
0.168	0.168	170.5	170.5	51.6667	51.6667	172	172
0.169	0.169	172	172	51.8333	51.8333	173	173
0.17	0.17	173	173	53.3333	53.3333	174.5	174.5
0.174	0.174	174	174	53.3333	53.3333	174.5	174.5
0.175	0.175	175.5	175.5	54.1667	54.1667	176	176
0.175	0.175	175.5	175.5	55.1667	55.1667	177	177
0.176	0.176	177	177	55.8333	55.8333	178.5	178.5
0.179	0.179	178.5	178.5	55.8333	55.8333	178.5	178.5
0.179	0.179	178.5	178.5	57.3333	57.3333	180	180
0.181	0.181	180	180	60	60	181	181
0.184	0.184	181.5	181.5	61	61	182	182
0.184	0.184	181.5	181.5	62.6667	62.6667	183	183
0.19	0.19	183	183	64.5	64.5	184	184
0.191	0.191	184	184	65	65	185.5	185.5
0.192	0.192	185	185	65	65	185.5	185.5
0.197	0.197	186.5	186.5	65.5	65.5	187	187
0.197	0.197	186.5	186.5	73	73	188	188
0.2	0.2	188	188	76.3334	76.3334	189	189
0.207	0.207	189	189	77.1667	77.1667	190	190
0.208	0.208	190	190	81.6667	81.6667	191	191
0.214	0.214	191	191	86	86	192	192
W=SUM Ri(+)			15756.5				16772.4
MEAN W			9168				9264
STD DEV W			764.9993				770.9994
Z			8.612426				9.73853

B. DATA SET TWO - PATTERN TWO

WILCOXON TEST PATTERN TWO

Pdi	ABS(Pdi)	RANK	Ri(+)	Hdi	ABS(Hdi)	RANK	Ri(+)
0	0			0	0		
0	0			0	0		
0	0			0	0		
0	0			0	0		
0	0			0	0		
0	0			0	0		
0	0			0	0		

-0.001	0.001	1.5	0	0	0		
0.001	0.001	1.5	1.5	0	0		
-0.002	0.002	5	0	0.1666	0.166	1	1
0.002	0.002	5	5	-0.3333	0.3333	2	
0.002	0.002	5	5	0.5	0.5	3	3
-0.002	0.002	5	0	0.8333	0.833	4	4
0.002	0.002	5	5	-0.8334	0.8334	5	0
0.003	0.003	8.5	8.5	-1	1	7	0
0.003	0.003	8.5	8.5	1	1	7	7
0.004	0.004	11.5	11.5	1	1	7	7
0.004	0.004	11.5	11.5	1.1667	1.1667	10.5	10.5
0.004	0.004	11.5	11.5	1.1667	1.1667	10.5	10.5
0.004	0.004	11.5	11.5	1.1667	1.1667	10.5	10.5
0.005	0.005	16	16	1.1667	1.1667	10.5	10.5
0.005	0.005	16	16	1.3333	1.3333	13	13
0.005	0.005	16	16	1.5	1.5	18.5	18.5
0.005	0.005	16	16	1.5	1.5	18.5	18.5
-0.005	0.005	16	0	1.5	1.5	18.5	18.5
0.006	0.006	22.5	22.5	1.5	1.5	18.5	18.5
0.006	0.006	22.5	22.5	1.5	1.5	18.5	18.5
0.006	0.006	22.5	22.5	1.5	1.5	18.5	18.5
0.006	0.006	22.5	22.5	1.5	1.5	18.5	18.5
0.006	0.006	22.5	22.5	-1.5	1.5	18.5	0
0.006	0.006	22.5	22.5	1.5	1.5	18.5	18.5
0.006	0.006	22.5	22.5	1.6666	1.6666	23	23
-0.006	0.006	22.5	0	1.6667	1.666	24	24
0.007	0.007	27	27	1.8333	1.8333	27	27
0.008	0.008	28.5	28.5	-1.8333	1.8333	27	0
0.008	0.008	28.5	28.5	1.8333	1.8333	27	27
0.009	0.009	32	32	1.8333	1.8333	27	27
0.009	0.009	32	32	1.8333	1.8333	27	27
0.009	0.009	32	32	-1.8334	1.8334	30	0
0.009	0.009	32	32	2	2	31.5	31.5
0.009	0.009	32	32	-2	2	31.5	0
-0.01	0.01	35.5	0	2.3333	2.333	34	34
0.01	0.01	35.5	35.5	2.3333	2.3333	34	34
-0.011	0.011	37	0	2.3333	2.333	34	34
-0.012	0.012	39	0	-2.5	2.5	36.5	0
0.012	0.012	39	39	-2.5	2.5	36.5	0
-0.012	0.012	39	0	3.1667	3.166	38	38
-0.013	0.013	42	0	3.6667	3.666	39	39
0.013	0.013	42	42	3.6667	3.6667	40	40
0.013	0.013	42	42	4	4	41	41
0.014	0.014	44	44	4.1667	4.1667	42	42
0.015	0.015	45	45	-4.3333	4.3333	46	0
0.016	0.016	46	46	5	5	44	44
0.017	0.017	47	47	5.3333	5.3333	45	45
0.018	0.018	48.5	48.5	-5.6667	5.6667	46	0
-0.018	0.018	48.5	0	5.8333	5.833	47	47
0.021	0.021	50.5	50.5	-5.8333	5.8333	48	0
-0.021	0.021	50.5	0	-6.5	6.5	50	0

-0.023	0.023	52	0	6.5	6.5	50	50
0.024	0.024	53.5	53.5	6.5	6.5	50	50
0.024	0.024	53.5	53.5	7.1667	7.1667	52	52
0.025	0.025	55	55	-7.8333	7.8333	53	0
0.026	0.026	56	56	-8.6667	8.6667	54	0
0.027	0.027	57.5	57.5	8.8334	8.8334	55	55
-0.027	0.027	57.5	0	-9.1666	9.166	56	0
0.028	0.028	59	59	-9.3333	9.3333	57	0
0.029	0.029	60.5	60.5	9.5	9.5	58	58
-0.029	0.029	60.5	0	-9.6666	9.666	60	0
-0.03	0.03	62.5	0	9.6667	9.666	60	60
-0.03	0.03	62.5	0	-9.6667	9.666	60	0
0.031	0.031	64.5	64.5	-9.8333	9.8333	62	0
-0.031	0.031	64.5	0	-10.1667	10.166	63	0
-0.032	0.032	66	0	10.6667	10.666	64	64
-0.033	0.033	67	0	-10.8334	10.833	65	0
-0.034	0.034	68	0	-11.1667	11.166	66	0
0.037	0.037	69	69	-11.5	11.5	68	0
0.038	0.038	69.5	69.5	11.5	11.5	68	68
0.038	0.038	69.5	69.5	-11.5	11.5	68	0
-0.039	0.039	72	0	11.6667	11.666	70	70
0.042	0.042	73.5	73.5	11.6667	11.6667	71	71
-0.042	0.042	73.5	0	11.8333	11.833	73	73
-0.043	0.043	75.5	0	-11.8333	11.8333	73	0
-0.043	0.043	75.5	0	11.8333	11.833	73	73
0.045	0.045	77	77	-12.8333	12.8333	76	0
-0.047	0.047	78	0	-12.8333	12.833	76	0
0.048	0.048	79.5	79.5	12.8333	12.8333	76	76
-0.048	0.048	79.5	0	-13	13	79.5	0
0.049	0.049	81	81	13	13	79.5	79.5
0.05	0.05	82	82	13	13	79.5	79.5
0.051	0.051	83	83	13	13	79.5	79.5
0.055	0.055	84	84	-13.6667	13.6667	82	0
0.056	0.056	85	85	-13.8333	13.8333	83	0
0.06	0.06	86	86	-14	14	84	0
0.061	0.061	87	87	-14.1666	14.1666	85	0
0.062	0.062	89	89	14.1667	14.1667	86	86
0.062	0.062	89	89	14.3333	14.3333	87	87
-0.062	0.062	89	0	-15	15	88	0
0.064	0.064	91	91	15.1667	15.1667	89.5	89.5
0.065	0.065	92	92	-15.1667	15.1667	89.5	0
0.066	0.066	93.5	93.5	-15.5	15.5	91	0
-0.066	0.066	93.5	0	16	16	92	92
0.067	0.067	95	95	16.5	16.5	93	93
-0.068	0.068	97	0	16.833	16.833	94	94
0.068	0.068	97	97	-17.1667	17.1667	95.5	0
0.068	0.068	97	97	17.1667	17.1667	95.5	95.5
-0.07	0.07	100	0	-17.1667	17.166	97	0
0.07	0.07	100	100	17.6666	17.6666	98	98
0.07	0.07	100	100	17.6667	17.6667	99	99
0.071	0.071	102	102	18	18	100.5	100.5

0.073	0.073	103	103	18	18	100.5	100.5
0.074	0.074	104	104	-18.1667	18.1667	102	0
-0.076	0.076	105.5	0	19	19	103	103
-0.076	0.076	105.5	0	19.8333	19.833	104	104
-0.077	0.077	107	0	-20	20	105	0
-0.078	0.078	108.5	0	20.1667	20.166	106	106
-0.078	0.078	108.5	0	20.3333	20.333	107	107
-0.08	0.08	110	0	20.5	20.5	108.5	108.5
0.085	0.085	111	111	20.5	20.5	108.5	108.5
0.086	0.086	112	112	21	21	110	110
0.09	0.09	113	113	21.3333	21.3333	111	111
0.091	0.091	115	115	21.5	21.5	112.5	112.5
0.091	0.091	115	115	21.5	21.5	112.5	112.5
-0.091	0.091	115	0	21.6667	21.666	114	114
-0.092	0.092	117.5	0	21.8333	21.833	115	115
0.092	0.092	117.5	117.5	-22.1667	22.1667	116	0
0.094	0.094	119.5	119.5	22.3333	22.3333	117	117
-0.094	0.094	119.5	0	22.5	22.5	118	118
-0.095	0.095	122	0	22.8333	22.833	119	119
0.095	0.095	122	122	23	23	120	120
-0.095	0.095	122	0	23.1667	23.166	121	121
-0.097	0.097	124	0	23.6667	23.666	123	123
0.098	0.098	126	126	23.8333	23.8333	124	124
0.098	0.098	126	126	24.1667	24.1667	125	125
0.098	0.098	126	126	-24.3333	24.3333	126	0
0.102	0.102	128	128	-24.5	24.5	127	0
-0.103	0.103	129	0	-26.3333	26.333	128	0
-0.104	0.104	130.5	0	-26.6667	26.666	129	0
0.104	0.104	130.5	130.5	-28.1666	28.1666	130	0
0.105	0.105	132	132	28.1667	28.1667	131	131
-0.109	0.109	133	0	-28.3333	28.3333	132	0
0.11	0.11	134.5	134.5	28.5	28.5	133.5	133.5
-0.11	0.11	134.5	0	-28.5	28.5	133.5	0
-0.111	0.111	136	0	28.6667	28.666	135	135
0.114	0.114	137	137	29	29	136	136
0.115	0.115	138	138	-29.3333	29.3333	137	0
0.117	0.117	139.5	139.5	-30.1666	30.1666	138	0
-0.117	0.117	139.5	0	30.1667	30.166	139	139
0.118	0.118	141	141	30.1667	30.1667	140	140
0.119	0.119	142	142	30.3333	30.3333	142	142
0.121	0.121	143	143	30.3333	30.3333	142	142
0.123	0.123	144.5	144.5	-30.3333	30.3333	142	0
-0.123	0.123	144.5	0	-30.3334	30.333	144	0
0.124	0.124	146	146	30.8333	30.8333	145	145
-0.125	0.125	147	0	31.1667	31.166	146	146
-0.13	0.13	148	0	-31.6667	31.666	147	0
0.141	0.141	149	149	31.6667	31.6667	148.5	148.5
0.142	0.142	150	150	31.6667	31.6667	148.5	148.5
0.145	0.145	152	152	31.8333	31.8333	150	150
-0.145	0.145	152	0	32	32	151	151
-0.145	0.145	152	0	-32.1667	32.166	152	0

0.146	0.146	154	154	-32.6666	32.6666	153.50	
0.148	0.148	155.5	155.5	-32.6666	32.6666	153.50	
-0.148	0.148	155.5	0	-32.8333	32.833	156	0
0.151	0.151	157	157	32.8333	32.8333	156	156
0.152	0.152	158	158	32.8333	32.8333	156	156
0.155	0.155	159	159	-34.5	34.5	158	0
0.161	0.161	160	160	34.8333	34.8333	159	159
-0.166	0.166	161	0	-35	35	160	0
0.167	0.167	162	162	35.1667	35.1667	161	161
0.172	0.172	164	164	35.3333	35.3333	163.5	163.5
-0.172	0.172	164	0	-35.3333	35.333	163.5	0
0.172	0.172	164	164	35.3333	35.3333	163.5	163.5
-0.173	0.173	166	0	-36.3333	36.333	163.5	0
-0.175	0.175	167	0	37.5	37.5	166	166
0.176	0.176	168	168	37.6667	37.6667	167	167
0.178	0.178	169	169	39.1667	39.1667	168	168
0.18	0.18	170	170	42.1667	42.1667	169	169
-0.184	0.184	171	0	43	43	170	170
-0.187	0.187	172	0	44.8333	44.833	171	171
-0.189	0.189	173	0	46.8333	46.833	172.5	172.5
-0.19	0.19	174	0	48.8333	48.833	172.5	172.5
0.192	0.192	175.5	175.5	49.3333	49.3333	174	174
0.192	0.192	175.5	175.5	50.5	50.5	175	175
0.194	0.194	177	177	51.5	51.5	176	176
0.197	0.197	178	178	52.8333	52.8333	177	177
0.204	0.204	179	179	54.1667	54.1667	178	178
0.206	0.206	180.5	180.5	56.5	56.5	179	179
-0.206	0.206	180.5	0	57.5	57.5	180	180
0.208	0.208	182	182	67	67	181	181
0.209	0.209	183	183	71.3333	71.3333	182	182
0.21	0.21	184	184	71.5	71.5	183	183
0.213	0.213	185	185	72.1666	72.1666	184	184
0.217	0.217	186.5	186.5	83.6666	83.6666	185	185
0.217	0.217	186.5	186.5	84.3333	84.3333	186	186
0.226	0.226	188	188	90	90	187	187
0.235	0.235	189	189	91.3333	91.3333	188	188
0.237	0.237	190	190	96.3333	96.3333	189	189
0.252	0.252	191	191	99.6667	99.6667	190	190
0.306	0.306	192	192	127.5	127.5	191	191
0.328	0.328	193	193	148.3333	148.3333	192	192

W=SUM Ri(+)	12388.5	13001.5
MEAN W	9360.5	9264
STD DEV W	777.015	770.9994
Z	3.896965	4.847605

C. DATA SET THREE - PATTERN THREE

WILCOXON TEST PATTERN THREE

Pdi	ABS(Pdi)	RANK	Ri(+)	Hdi	ABS(Hdi)	RANK	Ri(+)
0	0			0	0		
0	0			0	0		
0	0			0	0		
0	0			0	0		
0	0			0	0		
0	0			0	0		
0	0			0	0		
0	0			0	0		
0	0			0	0		
0	0			0	0		
0	0			0	0		
0	0			0	0		
0	0			0	0		
0	0			0	0		
0	0			0	0		
0	0			0.3333	0.3333	1	1
0	0			0.5	0.5	3	3
0	0			0.5	0.5	3	3
0.001	0.001	3.5	3.5	0.5	0.5	3	3
0.001	0.001	3.5	3.5	-0.8333	0.8333	6.5	0
-0.001	0.001	3.5	0	0.8333	0.8333	6.5	6.5
0.001	0.001	3.5	3.5	0.8333	0.8333	6.5	6.5
0.001	0.001	3.5	3.5	0.8333	0.8333	6.5	6.5
-0.001	0.001	3.5	0	1	1	9.5	9.5
0.002	0.002	11.5	11.5	1	1	9.5	9.5
0.002	0.002	11.5	11.5	-1.1667	1.1667	13	0
0.002	0.002	11.5	11.5	1.1667	1.1667	13	13
0.002	0.002	11.5	11.5	1.1667	1.1667	13	13
0.002	0.002	11.5	11.5	1.1667	1.1667	13	13
0.002	0.002	11.5	11.5	1.1667	1.1667	13	13
0.002	0.002	11.5	11.5	1.3333	1.3333	17.5	17.5
0.002	0.002	11.5	11.5	1.3333	1.3333	17.5	17.5
0.002	0.002	115	115	1.3333	1.3333	17.5	17.5
0.002	0.002	11.5	11.5	-1.3333	1.3333	17.5	0
-0.003	0.003	17	0	1.5	1.5	21.5	21.5
0.003	0.003	23	23	1.5	1.5	21.5	21.5
0.003	0.003	23	23	1.5	1.5	21.5	21.5
0.003	0.003	23	23	1.5	1.5	21.5	21.5
0.003	0.003	23	23	1.6667	1.6667	26.5	26.5
0.003	0.003	23	23	1.6667	1.6667	26.5	26.5
0.003	0.003	23	23	1.6667	1.6667	26.5	26.5
0.003	0.003	23	23	1.6667	1.6667	26.5	26.5
0.003	0.003	23	23	1.6667	1.6667	26.5	26.5
0.003	0.003	23	23	1.6667	1.6667	26.5	26.5
0.003	0.003	23	23	1.8333	1.8333	31	31
0.003	0.003	23	23	1.8333	1.8333	31	31
-0.003	0.003	23	0	-1.8333	1.8333	31	0

-0.004	0.004	34	0	2	2	33.5	33.5
0.004	0.004	34	34	2	2	33.5	33.5
0.004	0.004	34	34	-2.1666	2.1666	35.5	0
0.004	0.004	34	34	-2.1667	2.1667	35.5	0
0.004	0.004	34	34	2.5	2.5	37.5	37.5
0.004	0.004	34	34	2.5	2.5	37.5	37.5
0.004	0.004	34	34	-2.6666	2.6666	39	0
0.004	0.004	34	34	2.8333	2.8333	40.5	40.5
-0.004	0.004	34	0	2.8333	2.8333	40.5	40.5
0.005	0.005	40	40	2.8334	2.8334	42	42
0.005	0.005	40	40	-3	3	43	0
0.005	0.005	40	40	-3.1667	3.1667	44	0
-0.006	0.006	43.5	0	-3.3333	3.3333	45.5	0
0.006	0.006	43.5	43.5	3.3333	3.3333	45.5	45.5
-0.006	0.006	43.5	0	3.3334	3.3334	47	47
-0.006	0.006	43.5	0	-3.5	3.5	49	0
-0.007	0.007	46	0	3.5	3.5	49	49
-0.008	0.008	47.5	0	3.5	3.5	49	49
-0.008	0.008	47.5	0	4.3334	4.3334	51	51
0.009	0.009	50	50	4.6667	4.6667	52	52
0.009	0.009	50	50	-4.8334	4.8334	53	0
0.009	0.009	50	50	-5.1666	5.1666	54	0
0.01	0.01	52	52	5.5	5.5	55	55
0.011	0.011	54.5	54.5	-5.6667	5.6667	56	0
0.011	0.011	54.5	54.5	-5.8333	5.8333	57	0
0.011	0.011	54.5	54.5	-6	6	58	0
-0.011	0.011	54.5	0	6.3334	6.3334	59	59
0.012	0.012	57	57	-6.6667	6.6667	60.5	0
0.013	0.013	58	58	-6.6667	6.6667	60.5	0
-0.014	0.014	59	0	-7.1667	7.1667	62	0
0.015	0.015	62	62	7.5	7.5	63	63
0.015	0.015	62	62	-7.8333	7.8333	64	0
-0.015	0.015	62	0	-7.8334	7.8334	65	0
0.015	0.015	62	62	8.1666	8.1666	66	66
-0.015	0.015	62	0	8.3333	8.3333	67.5	67.5
0.016	0.016	66	66	8.3333	8.3333	67.5	67.5
0.016	0.016	66	66	-8.6666	8.6666	69	0
0.016	0.016	66	66	8.6667	8.6667	70.5	70.5
0.017	0.017	68.5	68.5	-8.6667	8.6667	70.5	0
0.017	0.017	68.5	68.5	9	9	72	72
-0.018	0.018	71.5	0	-9.5	9.5	73	0
0.018	0.018	71.5	71.5	-9.6667	9.6667	74	0
-0.018	0.018	71.5	0	10.1667	10.1667	76	76
0.018	0.018	71.5	71.5	10.1667	10.1667	76	76
0.02	0.02	74.5	74.5	-10.1667	10.1667	76	0
-0.02	0.02	74.5	0	-10.6666	10.6666	78	0
0.021	0.021	77.5	77.5	10.6667	10.6667	79	79
0.021	0.021	77.5	77.5	10.8333	10.8333	80.5	80.5
-0.021	0.021	77.5	0	10.8333	10.8333	80.5	80.5
-0.021	0.021	77.5	0	-10.8334	10.8334	82	0
0.022	0.022	80.5	80.5	11.1667	11.1667	83	83

0.022	0.022	80.5	80.5	11.3333	11.3333	84.5	84.5
0.024	0.024	82	82	11.3333	11.3333	84.5	84.5
0.025	0.025	83	83	11.5	11.5	86	86
-0.026	0.026	84	0	-12.1667	12.1667	87.5	0
0.027	0.027	86	86	12.1667	12.1667	87.5	87.5
-0.027	0.027	86	0	12.5	12.5	89	89
0.027	0.027	86	86	12.6667	12.6667	90	90
0.028	0.028	88.5	88.5	14	14	91	91
-0.028	0.028	88.5	0	14.1667	14.1667	92	92
-0.029	0.029	90.5	0	-14.5	14.5	93.5	0
0.029	0.029	90.5	90.5	14.5	14.5	93.5	93.5
-0.03	0.03	94.5	0	-15	15	95	0
0.03	0.03	94.5	94.5	15.5	15.5	96	96
-0.03	0.03	94.5	0	15.6667	15.6667	97	97
0.03	0.03	94.5	94.5	-16.1666	16.1666	98	0
0.03	0.03	94.5	94.5	16.1667	16.1667	99	99
-0.03	0.03	94.5	0	-16.5	16.5	100	0
0.031	0.031	98.5	98.5	16.8333	16.8333	101	101
0.031	0.031	98.5	98.5	17	17	102.5	102.5
-0.033	0.033	102	0	17	17	102.5	102.5
-0.033	0.033	102	0	17.1667	17.1667	104	104
-0.033	0.033	102	0	-17.3333	17.3333	105	0
-0.033	0.033	102	0	17.5	17.5	106	106
0.033	0.033	102	102	17.6667	17.6667	107	107
0.034	0.034	105	105	17.8333	17.8333	108	108
-0.035	0.035	107	0	-17.8334	17.8334	109	0
-0.035	0.035	107	0	-18.1666	18.1666	110	0
0.035	0.035	107	107	18.3333	18.3333	111	111
0.036	0.036	109	109	18.6667	18.6667	112	112
0.038	0.038	110	110	-19.1667	19.1667	113	0
-0.039	0.039	111	0	-19.5	19.5	114	0
0.041	0.041	112	112	19.8333	19.8333	115	115
-0.042	0.042	113	0	-20	20	116	0
0.043	0.043	115	115	-20.1667	20.1667	117.50	
-0.043	0.043	115	0	20.1667	20.1667	117.5	117.5
-0.043	0.043	115	0	20.5	20.5	119	119
0.044	0.044	117	117	-20.6667	20.6667	120	0
0.045	0.045	119	119	-20.8333	20.8333	121	0
-0.045	0.045	119	0	21.3333	21.3333	122	122
0.045	0.045	119	119	21.5	21.5	123.5	123.5
0.046	0.046	121	121	-21.5	21.5	123.5	0
0.048	0.048	122	122	-21.6667	21.6667	125	0
-0.049	0.049	123.5	0	-22	22	126	0
-0.049	0.049	123.5	0	22.1667	22.1667	127	127
-0.05	0.05	125	0	22.6666	22.6666	128	128
0.051	0.051	127	127	-22.8333	22.8333	129	0
-0.051	0.051	127	0	-23.3333	23.3333	130.50	
0.051	0.051	127	127	23.3333	23.3333	130.5	130.5
0.053	0.053	130	130	23.6667	23.6667	132	132
-0.053	0.053	130	0	23.8333	23.8333	133	133
-0.053	0.053	130	0	24	24	134	134

-0.054	0.054	132.5	0	-24.1667	24.1667	135	0
0.054	0.054	132.5	132.5	-24.5	24.5	136	0
0.055	0.055	134	134	-24.6666	24.6666	137	0
0.06	0.06	135	135	26	26	138	138
0.064	0.064	136	136	26.3333	26.3333	139	139
0.068	0.068	137.5	137.5	26.6666	26.6666	140	140
0.068	0.068	137.5	137.5	26.6667	26.6667	141	141
0.069	0.069	139	139	27.3333	27.3333	142	142
0.07	0.07	140.5	140.5	28.3333	28.3333	143	143
0.07	0.07	140.5	140.5	28.6667	28.6667	144	144
0.074	0.074	142	142	-28.8333	28.8333	145	0
0.075	0.075	143	143	29.5	29.5	146	146
0.076	0.076	144	144	31	31	147	147
0.077	0.077	145	145	-31.6667	31.6667	148	0
-0.078	0.078	146.5	0	-32.8333	32.8333	149	0
-0.078	0.078	146.5	0	-32.8334	32.8334	150	0
0.082	0.082	148.5	148.5	33.5	33.5	151.5	151.5
-0.082	0.082	148.5	0	-33.5	33.5	151.5	0
-0.084	0.084	150	0	33.6667	33.6667	153	153
-0.087	0.087	151	0	33.8333	33.8333	154	154
-0.089	0.089	152	0	33.8334	33.8334	155	155
-0.092	0.092	153	0	34	34	156.5	156.5
-0.096	0.096	154	0	34	34	156.5	156.5
-0.097	0.097	155	0	34.8333	34.8333	158	158
0.099	0.099	156	156	35.8333	35.8333	159	159
-0.1	0.1	157	0	-36	36	160	0
0.103	0.103	158	158	36.1667	36.1667	161	161
-0.104	0.104	159	0	36.6667	36.6667	162	162
-0.105	0.105	161	0	-37.5	37.5	163	0
-0.105	0.105	161	0	-38	38	164	0
-0.105	0.105	161	0	-39.6666	39.6666	165	0
0.106	0.106	163.5	163.5	-40.5	40.5	166	0
-0.106	0.106	163.5	0	-41.5	41.5	167	0
0.108	0.108	165	165	-41.8333	41.8333	168	0
-0.111	0.111	166.5	0	42.8333	42.8333	169	169
0.111	0.111	166.5	166.5	-43.1667	43.1667	170	0
-0.113	0.113	168	0	-43.3333	43.3333	171	0
0.116	0.116	169	169	-43.6667	43.6667	172	0
-0.117	0.117	170	0	-44.5	44.5	173	0
-0.125	0.125	171	0	-45	45	174	0
0.126	0.126	172	172	46.3333	46.3333	175	175
0.13	0.13	173	173	46.3334	46.3334	176	176
-0.138	0.138	174	0	48.1667	48.1667	177	177
0.139	0.139	175	175	53.1666	53.1666	178	178
0.145	0.145	176	176	57.5	57.5	179	179
0.172	0.172	177.5	177.5	59.1667	59.1667	180	180
0.172	0.172	177.5	177.5	66.1667	66.1667	181	181
0.174	0.174	179	179	67.8333	67.8333	182	182
0.179	0.179	180	180	68.3333	68.3333	183	183
0.19	0.19	181	181	75.3333	75.3333	184	184
0.191	0.191	182	182	77.6667	77.6667	185	185

W=SUM Ri(+)	9866.5	10435
MEAN W	8326.5	8602.5
STD DEV W	711.7083	729.3293
Z	2.163808	2.512582

D. DATA SET FOUR - PATTERN ONE, PATH TWO

WILCOXON TEST PATH 2 PATTERN ONE

Pdi	ABS(Pdi)	RANK	Ri(+)	Hdi	ABS(Hdi)	RANK	Ri(+)
0	0			0	0		
0	0			0	0		
0	0			0	0		
0	0			0	0		
0	0			0	0		
0	0			0	0		
0	0			-0.1667	0.1667	1	1
0	0			-0.6667	0.6667	2	2
-0.001	0.001	1	1	0.8333	0.833	3	3
0.002	0.002	3.5	3.5	1	1	4	4
0.002	0.002	3.5	3.5	1.5	1.5	5	5
0.002	0.002	3.5	3.5	-2.3334	2.3334	6	6
0.002	0.002	3.5	3.5	-2.6666	2.6666	7	7
0.003	0.003	6	6	-2.6667	2.6667	8	8
0.004	0.004	7	7	2.8333	2.8333	9	9
0.005	0.005	8	8	3	3	10	10
-0.006	0.006	9	9	-3.3333	3.333	11	11
-0.007	0.007	10.5	10.5	4	4	12	12
0.007	0.007	10.5	10.5	4.6666	4.6666	13	13
-0.008	0.008	13	13	4.6666	4.666	14	14
0.008	0.008	13	13	5	5	15	15
0.008	0.008	13	13	5.1667	5.1667	16	16
-0.009	0.009	16	16	-5.5	5.5	17.5	17.5
0.009	0.009	16	16	-5.5	5.5	17.5	17.5
0.009	0.009	16	16	5.8333	5.8333	19	19
0.014	0.014	18	18	-6	6	20	20
-0.015	0.015	19.5	19.5	6.1667	6.166	21	21
0.015	0.015	19.5	19.5	6.1667	6.1667	22	22
0.016	0.016	21	21	7	7	23	23
0.017	0.017	22.5	22.5	-7.3333	7.3333	24	24
0.017	0.017	22.5	22.5	7.5	7.5	25.5	25.5
0.019	0.019	24.5	24.5	7.5	7.5	25.5	25.5
0.019	0.019	24.5	24.5	7.6667	7.6667	27	27
0.02	0.02	26	26	7.8333	7.8333	28	28
0.021	0.021	27.5	27.5	8	8	29	29
0.021	0.021	27.5	27.5	8.1667	8.1667	30.5	30.5
0.023	0.023	29.5	29.5	-8.1667	8.1667	30.5	30.5
0.023	0.023	29.5	29.5	8.3333	8.3333	32	32

0.024	0.024	31	31	-8.5	8.5	33	33
-0.025	0.025	32.5	32.5	8.8333	8.833	34	34
0.025	0.025	32.5	32.5	-9	9	35.5	35.5
-0.027	0.027	34	34	9	9	35.5	35.5
-0.028	0.028	35.5	35.5	-9.3333	9.333	38	38
-0.028	0.028	35.5	35.5	9.3333	9.333	38	38
-0.029	0.029	37	37	9.3333	9.333	38	38
0.031	0.031	38	38	-9.3334	9.3334	40	40
-0.033	0.033	40	40	-9.5	9.5	41	41
0.033	0.033	40	40	9.6667	9.6667	42	42
-0.033	0.033	40	40	-9.8333	9.833	43	43
0.034	0.034	42	42	-9.8333	9.8333	44	44
0.037	0.037	43	43	10.1667	10.1667	45	45
-0.038	0.038	44.5	44.5	-10.3333	10.333	46	46
0.038	0.038	44.5	44.5	-10.6667	10.6667	47	47
0.04	0.04	46	46	11	11	48	48
0.042	0.042	47	47	-11.6666	11.6666	49	49
-0.044	0.044	49	49	-13.1667	13.166	50	50
0.044	0.044	49	49	13.6667	13.6667	51	51
0.044	0.044	49	49	14	14	52	52
-0.045	0.045	51	51	14.1666	14.166	53.5	53.5
-0.046	0.046	52.5	52.5	-14.1666	14.166	53.5	53.5
0.046	0.046	52.5	52.5	-14.6667	14.6667	55	55
-0.048	0.048	54.5	54.5	-15	15	56	56
-0.048	0.048	54.5	54.5	-15.1667	15.166	57	57
-0.051	0.051	56	56	15.5	15.5	58	58
-0.052	0.052	57.5	57.5	15.6667	15.666	59	59
-0.052	0.052	57.5	57.5	15.6667	15.666	60	60
-0.053	0.053	59.5	59.5	-16	16	61	61
0.053	0.053	59.5	59.5	17.3333	17.3333	62	62
-0.055	0.055	61.5	61.5	17.8333	17.833	63	63
0.055	0.055	61.5	61.5	-17.8334	17.8334	64	64
0.056	0.056	63	63	-18	18	65	65
0.057	0.057	65	65	-20	20	66	66
0.057	0.057	65	65	20.6667	20.6667	67	67
-0.057	0.057	65	65	-20.8333	20.833	68	68
0.058	0.058	67	67	-21	21	69	69
-0.059	0.059	68	68	21.6667	21.666	70	70
0.062	0.062	69.5	69.5	-21.8333	21.8333	71	71
-0.062	0.062	69.5	69.5	21.8333	21.833	72	72
0.063	0.063	71	71	-22.1667	22.1667	73	73
0.067	0.067	72.5	72.5	22.3333	22.3333	74	74
0.067	0.067	72.5	72.5	23.1666	23.1666	75	75
0.068	0.068	74.5	74.5	-23.3333	23.3333	76	76
0.068	0.068	74.5	74.5	24.3333	24.3333	77.5	77.5
0.07	0.07	76	76	-24.3333	24.3333	77.5	77.5
0.071	0.071	77	77	25	25	79.5	79.5
0.074	0.074	78	78	-25	25	79.5	79.5
-0.079	0.079	79	79	26.5	26.5	81	81
-0.082	0.082	80	80	26.6666	26.666	82	82
0.083	0.083	81	81	-27.1667	27.1667	83	83

0.084	0.084	82	82	-27.5	27.5	84	84
-0.085	0.085	83.5	83.5	-27.6667	27.666	85	85
-0.085	0.085	83.5	83.5	28.166	28.1666	86	86
0.087	0.087	85	85	28.6667	28.6667	87	87
0.089	0.089	86	86	28.8333	28.8333	88	88
-0.097	0.097	87	87	-28.8333	28.833	89	89
-0.099	0.099	88.5	88.5	29	29	90	90
0.099	0.099	88.5	88.5	29.6667	29.6667	91	91
-0.1	0.1	90.5	90.5	-29.8333	29.833	92	92
-0.1	0.1	90.5	90.5	30.6666	30.666	93	93
-0.104	0.104	92	92	31.1667	31.166	94.5	94.5
-0.105	0.105	93	93	31.6667	31.666	94.5	94.5
-0.106	0.106	94	94	32	32	96	96
0.107	0.107	95	95	-32.6667	32.6667	97	97
0.109	0.109	96	96	33.3333	33.3333	98	98
0.112	0.112	98	98	34.5	34.5	99	99
0.112	0.112	98	98	-35.8334	35.8334	100	100
0.112	0.112	98	98	37.1666	37.1666	101	101
-0.115	0.115	100	100	-38.1667	38.166	102	102
-0.118	0.118	101.5	101.5	40.8334	40.833	103	103
-0.118	0.118	101.5	101.5	-41.1667	41.166	104	104
0.12	0.12	103	103	42.3334	42.3334	105	105
-0.122	0.122	104	104	43.3334	43.333	106	106
0.123	0.123	105	105	45.5	45.5	107	107
-0.125	0.125	106	106	46.1667	46.166	108	108
0.127	0.127	107	107	47.3333	47.3333	109	109
0.128	0.128	108	108	47.5	47.5	110	110
-0.13	0.13	109	109	48	48	111	111
-0.131	0.131	110	110	48.3333	48.333	112.5	112.5
-0.132	0.132	111	111	48.3333	48.333	112.5	112.5
0.134	0.134	112.5	112.5	48.5	48.5	114	114
0.134	0.134	112.5	112.5	51.1667	51.1667	115	115
-0.138	0.138	114	114	51.6667	51.666	116	116
0.139	0.139	115	115	51.6667	51.6667	117	117
0.143	0.143	116	116	54.1667	54.1667	118	118
0.149	0.149	117	117	55.1667	55.1667	119	119
0.15	0.15	118	118	55.5	55.5	120	120
-0.151	0.151	119	119	56.6667	56.666	121	121
-0.157	0.157	120	120	58.1667	58.166	122	122
0.166	0.166	121	121	58.8333	58.8333	123	123
-0.167	0.167	122	122	59.8333	59.833	124	124
0.175	0.175	123	123	62.1667	62.1667	125	125
0.18	0.18	124	124	65	65	126	126
0.182	0.182	125	125	65.5	65.5	127	127
0.183	0.183	126	126	66.6667	66.6667	128	128
0.187	0.187	127	127	68	68	129	129
0.189	0.189	128	128	68.5	68.5	130	130
0.198	0.198	129	129	69.1667	69.1667	131	131
0.201	0.201	130	130	71.5	71.5	132	132
0.213	0.213	131	131	76.5	76.5	133	133
0.215	0.215	132	132	77.1666	77.1666	134	134

0.221	0.221	133	133	80.8333	80.8333	135	135
0.222	0.222	134	134	83.1667	83.1667	136	136
0.228	0.228	135	135	84.8333	84.8333	137	137
0.236	0.236	136	136	85.6667	85.6667	138	138
0.237	0.237	137	137	86.1667	86.1667	139	139
0.24	0.24	138	138	87.3333	87.3333	140	140
0.244	0.244	139	139	88	88	141	141
0.247	0.247	140	140	90.1667	90.1667	142	142
0.253	0.253	141	141	91.1666	91.1666	143	143
0.259	0.259	142.5	142.5	92.5	92.5	144	144
0.259	0.259	142.5	142.5	92.6667	92.6667	145	145
0.264	0.264	144	144	94.5	94.5	146	146
0.269	0.269	145	145	96.6667	96.6667	147	147
0.272	0.272	146	146	97.3334	97.3334	148	148
0.273	0.273	147	147	98.3333	98.3333	149	149
0.275	0.275	148	148	103.6667	103.6667	150	150
0.278	0.278	149	149	106.8334	106.8334	151	151
0.279	0.279	150	150	116.8334	116.8334	152	152
0.286	0.286	151	151	127.3333	127.3333	153	153
0.298	0.298	152	152	128.5	128.5	154	154
0.305	0.305	153	153	129.8333	129.8333	155	155
0.308	0.308	154.5	154.5	136	136	156	156
0.308	0.308	154.5	154.5	143.3333	143.3333	157	157
0.31	0.31	156	156	215.8333	215.8333	158	158
0.311	0.311	157	157	239.5	239.5	159	159
0.312	0.312	158	158	242	242	160	160
0.317	0.317	159	159	246.6667	246.6667	161	161
0.32	0.32	160	160	250	250	162	162
0.324	0.324	161	161	253.3334	253.3334	163	163
0.333	0.333	162	162	254	254	164	164
0.343	0.343	163	163	267	267	165	165
0.356	0.356	164.4	164.4	270	270	166	166
0.356	0.356	164.5	164.5	284.1667	284.1667	167	167
0.358	0.358	166.5	166.5	308.3334	308.3334	168	168
0.358	0.358	166.5	166.5	318.1667	318.1667	169	169
0.361	0.361	168	168	331	331	170	170
0.363	0.363	169	169	334.5	334.5	171	171
0.381	0.381	170	170	500.6667	500.6667	172	172
0.392	0.392	171	171	520.8333	520.8333	173	173
0.396	0.396	172	172	540.8334	540.8334	174	174
0.398	0.398	173.5	173.5	555.1667	555.1667	175.5	175.5
0.398	0.398	173.5	173.5	555.1667	555.1667	175.5	175.5
0.399	0.399	175	175	562.8333	562.8333	177	177
0.415	0.415	176	176	565.3333	565.3333	178	178
0.416	0.416	177	177	569.6667	569.6667	179	179
0.421	0.421	178	178	570.1667	570.1667	180	180
0.429	0.429	179	179	571.8333	571.8333	181	181
0.431	0.431	180	180	574.1667	574.1667	182	182
0.434	0.434	181	181	576.1666	576.1666	183	183
0.439	0.439	182	182	576.8333	576.8333	184	184
0.444	0.444	183.5	183.5	584.1667	584.1667	185	185

0.444	0.444	183.5	183.5	588	588	186	186
0.453	0.453	185	185	590.1667	590.1667	187	187
0.455	0.455	186	186	590.5	590.5	188.5	188.5
0.465	0.465	187	187	590.5	590.5	188.5	188.5
0.467	0.467	188	188	594.1667	594.1667	192.5	192.5
0.479	0.479	189	189	594.1667	594.1667	192.5	192.5
0.481	0.481	190	190	594.1667	594.1667	192.5	192.5
0.482	0.482	191	191	594.1667	594.1667	192.5	192.5
0.526	0.526	192	192	594.8333	594.8333	194	194
W=SUM Ri(+)			18527.9				18916
MEAN W			9264				9457.5
STD DEV W			770.9994				783.046
Z			12.01544				12.0791

E. DATA SET FIVE - PATTERN ONE, PATH THREE

WILCOXON TEST PATH 3 PATTERN ONE

Pdi	ABS(Pdi)	RANK	Ri(+)	Hdi	ABS(Hdi)	RANK	Ri(+)
-0.001	0.001	1	0	0.8333	0.8333	1	1
0.002	0.002	2	2	-1.3333	1.3333	2	0
0.003	0.003	3	3	-1.3334	1.3334	3	0
-0.006	0.006	4	0	-2	2	4	0
0.008	0.008	6	6	2.5	2.5	5	5
-0.008	0.008	6	0	-3.1667	3.1667	6	0
0.008	0.008	6	6	3.3333	3.3333	7	7
-0.018	0.018	8	0	4	4	8	8
-0.021	0.021	9	0	-6	6	9	0
0.029	0.029	10	10	7.5	7.5	10	10
-0.03	0.03	11	0	9	9	11	11
-0.036	0.036	12	0	9.1667	9.1667	12	12
0.037	0.037	13	13	9.6667	9.6667	13	13
0.04	0.04	14	14	13.8334	13.8334	14	14
0.041	0.041	16	16	14	14	15	15
0.041	0.041	16	16	-14.1666	14.1666	16	0
0.041	0.041	16	16	14.1667	14.1667	17	17
-0.043	0.043	18	0	15.6667	15.6667	18	18
0.046	0.046	19	19	16.8333	16.8333	19	19
-0.047	0.047	20	0	16.8334	16.8334	20	20
0.049	0.049	21	21	-17	17	21	0
0.05	0.05	22	22	18	18	22	22
0.051	0.051	23	23	18.5	18.5	23	23
0.053	0.053	24	24	18.6667	18.6667	24	24
0.055	0.055	25.5	25.5	19	19	25	25
0.055	0.055	25.5	25.5	19.8333	19.8333	26	26
0.056	0.056	27	27	20.6667	20.6667	27	27
0.057	0.057	28	28	20.8334	20.8334	28	28
0.064	0.064	29	29	21	21	29	29

0.069	0.069	30	30	22.3333	22.3333	30	30
0.075	0.075	31	31	-22.5	22.5	31	0
0.081	0.081	32.5	32.5	23	23	32	32
0.081	0.081	32.5	32.5	24.5	24.5	33	33
-0.083	0.083	34	0	24.8333	24.8333	34	34
-0.086	0.086	35	0	25.3333	25.3333	35	35
0.087	0.087	36	36	25.5	25.5	36	36
0.094	0.094	37	37	25.8333	25.8333	37	37
0.098	0.098	38	38	25.8334	25.8334	38	38
0.101	0.101	39	39	27.3333	27.3333	39	39
0.108	0.108	40	40	27.6667	27.6667	40	40
0.109	0.109	40	40	28.1667	28.1667	41	41
-0.11	0.11	42	0	29	29	42	42
0.112	0.112	43.5	43.5	29.1666	29.1666	43	43
0.112	0.112	43.5	43.5	29.1667	29.1667	44	44
0.113	0.113	46	46	29.3333	29.3333	45	45
0.113	0.113	46	46	30.6666	30.6666	46	46
0.113	0.113	46	46	30.6667	30.6667	47.5	47.5
0.114	0.114	48.5	48.5	30.6667	30.6667	47.5	47.5
0.114	0.114	48.5	48.5	-32	32	49.5	0
0.12	0.12	50	50	32	32	49.5	49.5
0.121	0.121	51	51	32.3333	32.3333	51	51
0.122	0.122	52	52	32.8333	32.8333	52	52
0.123	0.123	53	53	33.6666	33.6666	53	53
0.125	0.125	54.5	54.5	33.8333	33.8333	54	54
0.125	0.125	54.5	54.5	34.1666	34.1666	55	55
0.126	0.126	56	56	34.6667	34.6667	57	57
0.127	0.127	57	57	34.6667	34.6667	57	57
0.132	0.132	58	58	34.6667	34.6667	57	57
0.133	0.133	59	59	34.8333	34.8333	59	59
0.138	0.138	60	60	35.3333	35.3333	60	60
0.14	0.14	61.5	61.5	36.3334	36.3334	61	61
0.14	0.14	61.5	61.5	36.8334	36.8334	62	62
0.142	0.142	63	63	37.6667	37.6667	63	63
0.143	0.143	64.5	64.5	37.8333	37.8333	64	64
0.143	0.143	64.5	64.5	38	38	65	65
0.146	0.146	66.5	66.5	38.5	38.5	66	66
-0.146	0.146	66.5	0	38.6667	38.6667	67	67
0.147	0.147	68	68	38.8333	38.8333	68	68
0.148	0.148	69	69	39.3333	39.3333	69	69
0.149	0.149	70	70	41	41	70	70
0.152	0.152	72	72	41.1667	41.1667	71.5	71.5
0.152	0.152	72	72	41.1667	41.1667	71.5	71.5
0.152	0.152	72	72	41.3334	41.3334	73	73
0.153	0.153	74	74	41.5	41.5	75	75
0.154	0.154	75	75	41.5	41.5	75	75
0.155	0.155	76	76	41.5	41.5	75	75
0.157	0.157	77	77	41.6666	41.6666	77.5	77.5
0.16	0.16	78	78	41.6666	41.6666	77.5	77.5
0.166	0.166	79.5	79.5	41.8333	41.8333	79	79
0.166	0.166	79.5	79.5	42.1667	42.1667	80	80

0.167	0.167	81	81	42.6666	42.6666	81	81
0.169	0.169	82.5	82.5	43	43	82	82
0.169	0.169	82.5	82.5	43.1667	43.1667	83	83
0.17	0.17	84	84	43.5	43.5	84	84
0.174	0.174	85	85	43.6667	43.6667	85	85
0.178	0.178	86	86	44	44	86	86
0.179	0.179	87	87	44.5	44.5	87.5	87.5
0.18	0.18	88.5	88.5	44.5	44.5	87.5	87.5
0.18	0.18	88.5	88.5	44.6666	44.6666	89	89
0.185	0.185	90	90	45	45	91	91
0.19	0.19	91	91	45	45	91	91
0.194	0.194	92	92	45	45	91	91
0.195	0.195	93	93	45.1666	45.1666	93	93
0.196	0.196	94	94	45.3333	45.3333	94	94
0.198	0.198	95	95	45.8333	45.8333	95	95
0.199	0.199	96.5	96.5	46.5	46.5	96	96
0.199	0.199	96.5	96.5	47.5	47.5	97	97
0.2	0.2	98	98	47.6667	47.6667	98	98
0.201	0.201	99	99	48.3333	48.3333	99	99
0.202	0.202	100	100	48.6667	48.6667	100.5	100.5
0.204	0.204	101	101	48.6667	48.6667	100.5	100.5
0.205	0.205	102	102	49.3333	49.3333	102	102
0.206	0.206	104	104	49.3334	49.3334	103	103
0.206	0.206	104	104	49.5	49.5	104	104
0.206	0.206	104	104	50.3333	50.3333	105	105
0.208	0.208	106	106	50.6667	50.6667	106	106
0.21	0.21	107	107	51	51	107	107
0.211	0.211	108	108	51.5	51.5	108	108
0.213	0.213	109	109	51.6666	51.6666	109	109
0.214	0.214	110	110	51.8333	51.8333	110	110
0.215	0.215	111	111	51.8334	51.8334	111	111
0.216	0.216	112	112	52.3334	52.3334	112	112
0.218	0.218	113	113	52.8334	52.8334	113	113
0.22	0.22	114	114	53	53	114	114
0.222	0.222	115	115	53.3333	53.3333	115	115
0.224	0.224	116.5	116.5	54.1666	54.1666	116	116
0.224	0.224	116.5	116.5	54.3333	54.3333	117	117
0.226	0.226	118	118	55	55	118.5	118.5
0.228	0.228	120	120	55	55	118.5	118.5
0.228	0.228	120	120	55.1667	55.1667	120	120
0.228	0.228	120	120	55.6667	55.6667	121	121
0.229	0.229	122	122	57	57	122	122
0.23	0.23	123.5	123.5	57.1667	57.1667	123	123
0.23	0.23	123.5	123.5	57.5	57.5	124	124
0.231	0.231	125	125	57.8334	57.8334	125	125
0.232	0.232	126	126	58	58	127	127
0.235	0.235	127.5	127.5	58	58	127	127
0.235	0.235	127.5	127.5	58	58	127	127
0.237	0.237	129	129	58.6666	58.6666	129	129
0.239	0.239	130	130	58.8333	58.8333	130	130
0.243	0.243	131	131	59.3333	59.3333	131	131

0.245	0.245	132	132	59.5	59.5	132	132
0.246	0.246	133	133	60	60	133	133
0.247	0.247	135	135	60.1666	60.1666	134	134
0.247	0.247	135	135	60.1667	60.1667	135.5	135.5
0.247	0.247	135	135	60.1667	60.1667	135.5	135.5
0.248	0.248	137.5	137.5	60.3333	60.3333	137	137
0.248	0.248	137.5	137.5	60.5	60.5	138	138
0.249	0.249	139	139	61.3333	61.3333	139	139
0.251	0.251	140	140	61.5	61.5	140	140
0.252	0.252	141	141	61.8333	61.8333	141	141
0.253	0.253	142.5	142.5	62.5	62.5	142.5	142.5
0.253	0.253	142.5	142.5	62.5	62.5	142.5	142.5
0.254	0.254	144	144	62.6666	62.6666	144	144
0.255	0.255	145	145	62.8333	62.8333	145	145
0.257	0.257	146.5	146.5	63.3333	63.3333	146	146
0.257	0.257	146.5	146.5	63.8333	63.8333	147.5	147.5
0.258	0.258	148.5	148.5	63.8333	63.8333	147.5	147.5
0.258	0.258	148.5	148.5	64.8333	64.8333	150	150
0.259	0.259	150.5	150.5	64.8333	64.8333	150	150
0.259	0.259	150.5	150.5	64.8333	64.8333	150	150
0.26	0.26	152	152	65	65	152.5	152.5
0.261	0.261	153.5	153.5	65	65	152.5	152.5
0.261	0.261	153.5	153.5	65.1667	65.1667	154	154
0.263	0.263	155	155	65.3333	65.3333	155.5	155.5
0.264	0.264	157	157	65.3333	65.3333	155.5	155.5
0.264	0.264	157	157	65.5	65.5	157	157
0.264	0.264	157	157	65.6667	65.6667	158	158
0.268	0.268	159	159	66.1667	66.1667	159	159
0.271	0.271	160	160	66.3333	66.3333	160	160
0.272	0.272	161	161	67.1667	67.1667	161	161
0.274	0.274	162	162	67.5	67.5	162.5	162.5
0.276	0.276	163	163	67.5	67.5	162.5	162.5
0.278	0.278	164	164	68	68	164.5	164.5
0.279	0.279	165.5	165.5	68	68	164.5	164.5
0.279	0.279	165.5	165.5	68.1667	68.1667	166	166
0.28	0.28	167	167	68.5	68.5	167.5	167.5
0.282	0.282	168.5	168.5	68.5	68.5	167.5	167.5
0.282	0.282	168.5	168.5	69	69	169	169
0.285	0.285	170	170	69.3333	69.3333	170.5	170.5
0.287	0.287	171	171	69.3333	69.3333	170.5	170.5
0.291	0.291	172	172	69.8333	69.8333	172	172
0.292	0.292	173	173	70.1667	70.1667	174	174
0.295	0.295	174	174	70.1667	70.1667	174	174
0.296	0.296	175	175	70.1667	70.1667	174	174
0.297	0.297	176	176	70.5	70.5	176	176
0.298	0.298	177	177	70.8333	70.8333	177	177
0.299	0.299	179	179	71.1666	71.1666	178	178
0.299	0.299	179	179	71.5	71.5	179	179
0.299	0.299	179	179	72	72	180	180
0.301	0.301	181.5	181.5	72.1667	72.1667	181	181
0.301	0.301	181.5	181.5	72.3333	72.3333	182.5	182.5

0.302	0.302	183	183	72.3333	72.3333	182.5	182.5
0.307	0.307	184	184	72.5	72.5	184	184
0.311	0.311	185	185	72.6667	72.6667	185	185
0.315	0.315	186	186	73.1667	73.1667	186	186
0.317	0.317	187	187	73.3333	73.3333	187.5	187.5
0.318	0.318	188	188	73.3333	73.3333	187.5	187.5
0.32	0.32	189	189	73.5	73.5	189.5	189.5
0.322	0.322	190	190	73.5	73.5	189.5	189.5
0.326	0.326	191	191	73.8334	73.8334	191	191
0.331	0.331	192.5	192.5	74.5	74.5	192	192
0.331	0.331	192.5	192.5	76.3333	76.3333	193.5	193.5
0.335	0.335	194	194	76.3333	76.3333	193.5	193.5
0.349	0.349	195	195	77	77	195	195
0.351	0.351	196	196	78.1667	78.1667	196	196
0.359	0.359	197	197	81.3333	81.3333	197	197
0.368	0.368	198	198	81.5	81.5	198	198
0.375	0.375	199	199	84.6667	84.6667	199	199
0.403	0.403	200	200	88.8333	88.8333	200	200
W=SUM Ri(+)			19832.5				19958.5
MEAN W			10050				10050
STD DEV W			820.5791				820.5791
Z			11.92146				12.07501

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Implementation and analysis of a smart submarine in the Active Sonobuoy Model.

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